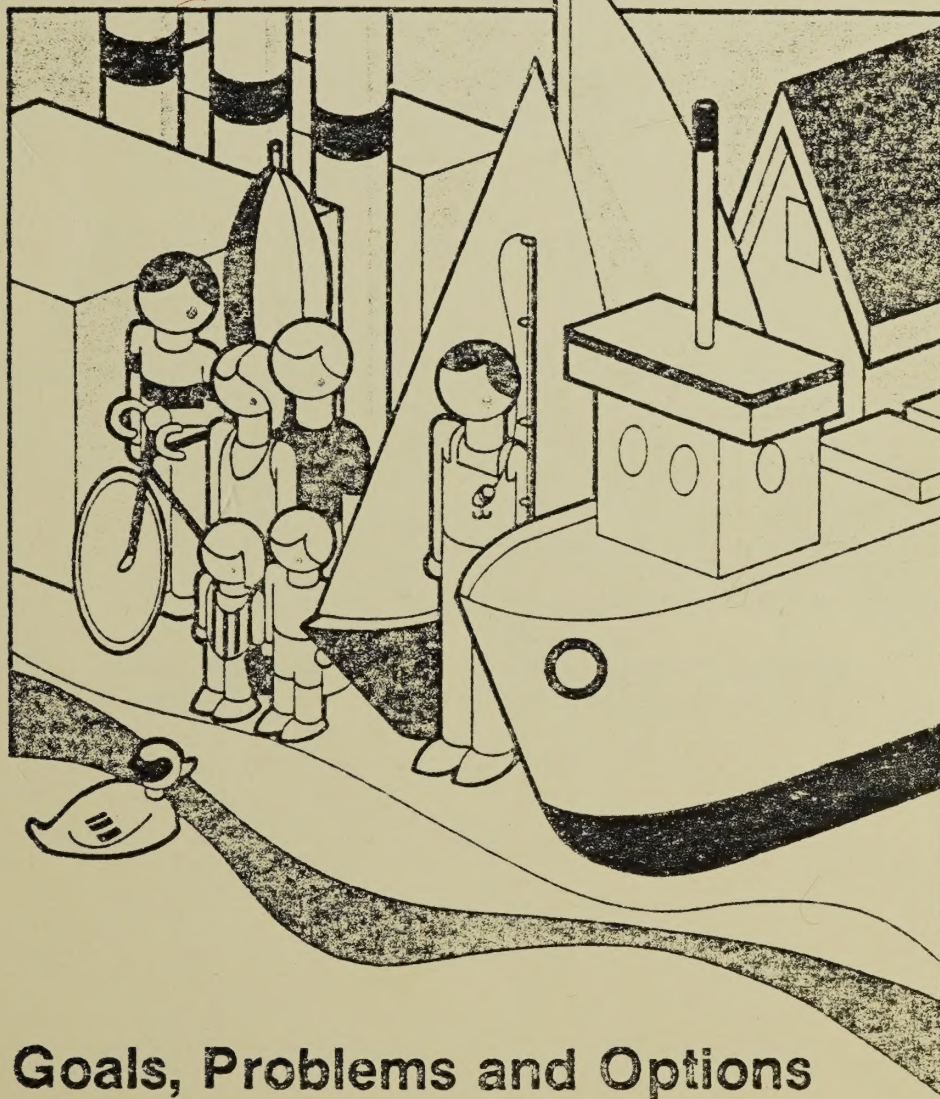


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Remedial Action Plan for Hamilton Harbour



Goals, Problems and Options

Discussion Document, March 1988

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GOVERNMENT DOCUMENTS

A
DISCUSSION DOCUMENT
of the
GOALS, PROBLEMS AND OPTIONS
for the
HAMILTON HARBOUR
REMEDIAL ACTION PLAN

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March, 1988

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I SYNOPSIS

I.1 INTRODUCTION

The International Joint Commission (IJC), has identified 42 Areas of Concern, 17 of which are located in Ontario. In 1986, the governments of Canada and Ontario committed themselves to developing Remedial Action Plans (RAPs) for these areas. The Hamilton Harbour RAP writing team was appointed and assigned the task of preparing a RAP in consultation with the public.

The RAP writing team is composed of members from the following agencies:

- * Environment Canada (DOE)
- * Environment Ontario (MOE)
- * The Department of Fisheries and Oceans (DFO)
- * The Ministry of Natural Resources (MNR)
- * The Ministry of Agriculture and Food (MAF)
- * The Royal Botanical Gardens (RBG)

Hamilton Harbour was recognized as a polluted body of water long before 1986. Since 1850 a significant loss of wildlife habitat has occurred around the harbour as a result of shoreline filling. By the 1960s, as surrounding communities grew, increased municipal and industrial discharges caused serious pollution problems in the harbour.

In the 1970s, measures to control the pollution were undertaken. The results of these measures have become evident in a number of ways:

- * several species of birds have returned to the harbour;
- * reproductive failures and deformities no longer occur in fish eating birds;
- * the number and diversity of fish species is increasing;
- * improvements have been documented in the number and type of worms inhabiting the sediment at the bottom of the harbour;
- * 42 species of fish are now successfully reproducing in the harbour, and;
- * seven sport fish species in the harbour can be eaten with no restrictions.

These improvements are the result of the approximately \$300 million that has been spent by industries and all levels of government on pollution abatement programs.

While improvements have been made in water quality, a number of remaining problems still exist:

- * wildlife habitat has been lost;
- * incidents of lead contamination and botulism in waterfowl have occurred;
- * birds which live in colonies may lose their habitat due to development;
- * ammonia concentrations are high;
- * for two months in the summer, oxygen levels are low in the deeper waters;
- * sediments in the harbour may represent a source of contaminants;
- * there are eating restrictions for large specimens of five fish species in the harbour, and;
- * poor water clarity limits fish habitat, aquatic plant growth and swimming.

The participation of the public is essential in bringing together the economic, environmental and social concerns of the communities surrounding the harbour. To meet this need, Environment Canada and Environment Ontario invited organizations, industry, and local government representatives who have an interest in the harbour to participate in a stakeholders group. During 1986 and 1987, the stakeholders identified their principles and goals necessary to restore beneficial uses to the harbour. Actions to solve the remaining water quality problems in the harbour depend on the kinds of uses which the stakeholders have identified.

The stakeholders identified specific goals based on the principle of an ecosystem approach and the philosophy of zero discharge of persistent toxic substances and secondary principles of human health, public acceptance and support, and aesthetics. The stakeholders' goals are related to recreational boating, water sports, shipping and navigation, industrial uses for water intakes and discharges, a waste water receiving body, fisheries, wildlife and habitat appreciation, swimming and use as an educational resource. The stakeholders' principles and goals are stated in the Stakeholders Interim Report of 1986 and are listed in Chapter 3.

The following section identifies the current conditions which must be overcome in order to achieve the stakeholders' goals.

I.2 LIMITATIONS TO ACHIEVING STAKEHOLDER GOALS

All the stakeholders' goals can be achieved by addressing their three key goals for fish, wildlife and swimming. Water quality, habitat loss and limited access are common limitations to achieving these goals. Many of the limitations are interrelated.

I.2.1 Ammonia Concentration

The levels of ammonia in the spring, exceed the provincial Water Quality Objective for the protection of aquatic life. The levels are so high they are toxic to fish. Bacteria convert the ammonia to nitrate during the summer which eliminates the problem of toxicity. However, 40% of the oxygen is used up adding to the problem of low oxygen.

I.2.2 Habitat for Fish

In addition to clean, well oxygenated water, fish require an abundance of plants. However, plants grow in only half of the nearshore areas suitable for sport fish habitat. Also, warm water fish are dominated by less desirable species (such as carp and white perch) which destroy the existing plant life, and compete for food and habitat.

Pike have specific needs for reproductive habitat. There are insufficient spawning and nursery areas for pike.

I.2.3 Water Clarity and Suspended Solids

Continuous exposure to concentrations of suspended solids above 25 milligrams per litre is harmful to fish. Shallow water areas of the harbour have concentrations of suspended solids which exceed this level.

Water clarity decreases with greater concentrations of algae and suspended solids. Algae is responsible for 10 to 30% of the total water clarity impairment in Hamilton Harbour and for less than 10% of the impairment in Cootes Paradise. The remaining problem is due to suspended solids and silt.

Nearshore water clarity is reduced further by wave action, resulting in the resuspension of silt, by the behaviour of carp, and from stream inputs of silt. Poor water clarity limits aquatic plants to 64 hectares.

I.2.4 Oxygen Concentrations

Oxygen concentration in deep water is insufficient to support fish during two months in the summer. Therefore, cold water fish must leave the harbour during these months. Warm

water fish such as bass and pike are not limited to the deep water. However, maintaining oxygen levels is important for supporting bottom fauna which are a source of food for the fish.

Improved oxygen levels will also inhibit the release of toxic metals and phosphorus back into the water from the sediments and enhance decay of organic material.

I.2.5 Contaminants

MOE and MNR annually publish a Guide to Eating Sport Fish in Ontario. There are fish consumption restrictions on large specimens of five out of 12 sport fish species found in Hamilton Harbour. Because these species are not permanent residents of the harbour, the contaminant content in the fish may not have come from Hamilton Harbour alone.

I.2.6 Wildlife Habitat

I.2.6.1 Loss of Wetlands

Wetlands contribute to the overall health of the ecosystem and provide the habitat necessary for a balanced and diverse wildlife population. The Canadian Wildlife Service ranks the west end of Lake Ontario, including Hamilton Harbour, as the second most important waterfowl staging area in Lake Ontario. It is also the fourth most important area on the lower Great Lakes. However, Hamilton Harbour has lost 80% of its original wetlands. Increasing the amount of wetlands in Hamilton Harbour is important for local wildlife and general bird populations.

I.2.6.2 Water Bird Colonies

Nesting habitat for water birds which live in colonies such as terns and cormorants now exists in the east end of the harbour in an area built and used for disposal of dredged sediments. However, the site will be at capacity by the year 2000, thus threatening the future of the existing waterbird colony.

I.2.6.3 Clean Wildlife Habitat

Large numbers of migratory waterfowl stay over winter in Windermere Basin because of the warm water and abundance of food. However, contaminants in the sediment could be picked up by the birds through the food chain. Recent incidents of bird deaths have been attributed to lead contamination and botulism. Clean up of this shallow basin is important for a healthy waterfowl population.

I.2.7 Limitations To Swimming

There are four limitations to achieving the goal of swimming in Hamilton Harbour:

- * data on bacterial levels indicate there may be a health risk to swimmers in the nearshore water;
- * water in the nearshore is too cloudy to permit swimming;
- * there is limited safe access to appropriate swimming areas in the harbour, and;
- * a by-law makes it illegal to swim in the harbour.

I.3 REMEDIAL OPTIONS TO RESTORE USES

In order to restore beneficial uses of the harbour, options were considered that would reduce or eliminate the limiting factors for achieving the stakeholders' goals. Some of the options listed are experimental in nature.

I.3.1 Ammonia Concentrations

In, 1987 ammonia loadings to the harbour were 7500 kilograms per day. In order to eliminate the toxic concentrations of ammonia and improve oxygen levels, a 50% reduction in ammonia discharges is needed. The Hamilton and Burlington sewage treatment plants (STP) are the largest sources of ammonia. Reductions of 50% would require capital costs of \$3 million to Hamilton and of \$6 million to Burlington and would require annual operating costs of \$250,000.

Actions already underway by Stelco and Dofasco will reduce their discharges of ammonia from 870 to 170 kilograms per day. This will cost the companies \$13 million.

Retention and treatment of combined sewer overflows (CSO's) could further reduce ammonia loadings for the CSOs from 200 to 20 kilograms per day. One retention basin has been constructed which addresses 25% of the problem. There are 25 other CSOs which still have to be controlled. The Regional Municipality of Hamilton-Wentworth plans to control all its combined sewer overflows over the next 20 to 40 years at a cost of \$60 million. A computerized system to optimize the storage capacity of the present sewer system could reduce the number and size of any retention basins needed. A pilot project is underway to assess how well the system will work.

I.3.2 Habitats for Fish

Creating habitat is as important to the fishery goal as improving water quality. The following options are based on increasing the number of desirable sport fish such as bass and pike. This will require creating suitable reproduction and nursery habitats. Creating reproduction habitat for bass requires improving the existing adult habitat. Pike require separate and different habitat for spawning, nursery and adult use.

Construction of all the habitat projects listed below could result in a total of approximately 120 hectares of sport fish habitat. Construction costs could be \$3 million with annual maintenance costs of \$100,000. These options have been suggested but detailed plans and feasibility studies have not been undertaken.

Restoration of suitable habitats for bass and pike to reproduce and develop could be attempted in five areas. They are discussed in order of importance.

I.3.2.1 Grindstone Creek Above Valley Inn Road

The available area totals 17 hectares. Pike currently reproduce in 3.7 hectares, and use a nursery area of one hectare. Increasing the spawning area by one hectare and providing a nursery habitat of an additional 1.3 hectares could produce an additional 1500 to 3000 fingerlings. Increasing the habitat in this area is estimated to cost \$100,000, with an annual maintenance cost of \$10,000.

I.3.2.2 Cootes Paradise

Pike reproduction and nursery habitats do not exist in Cootes Paradise. The bass habitat is limited due to the lack of hiding places and aquatic plants. A bermed cell specifically for fish reproduction is possible between Bulls Point and Princess Point. Studies done at other areas indicate that bass reproduction could occur at the rate of 30 kilograms of bass per hectare, per year.

Incorporating pike reproduction and nursery habitats in the design would require water level control and a fish ladder. A cell providing 100 hectares of habitat is estimated to cost \$1 million, with annual maintenance costs of \$50,000.

I.3.2.3 Southwest Corner of the Harbour

The southwest shore between the Desjardins Canal and the former Lax property is an important sport fish habitat. Currently four hectares of adult pike and bass habitat exist along this shore. Increasing this area to 35 hectares would be possible by land filling to shape the shore into embayments. These embayments could also make good public fishing and swimming sites. Construction costs are estimated to be \$1.7 million, with annual maintenance costs of \$30,000.

I.3.2.4 Burlington North Shore

The north shore provides the largest potential for adult habitat in the harbour. The lack of hiding places along the north shore is limiting fish populations. Placing 12 sets of artificial reefs could create 12 hectares of adult habitat. Capital costs are estimated to be \$10,000 for each reef with annual maintenance costs of \$5,000 for each reef. The target for fish production is 600 kilograms per year.

I.3.2.5 Grindstone Creek Delta

Building islands in the Grindstone Creek Delta will reduce turbidity and encourage plant growth. The area would provide 22 hectares for bass and pike reproduction habitat. It is estimated it could produce up to 1100 kilograms of sport fish per year. The construction costs are estimated to be \$200,000 with an annual maintenance cost of \$10,000.

I.3.3 Water Clarity and Suspended Solids Improvements

Improvements in water clarity require reducing silt input, minimizing resuspension of bottom sediments and control of phosphorus loadings to limit algal growth, .

A pilot project for improving phosphorus removal is underway at the Hamilton STP. If successful approximately 50% of the discharged phosphorus could be removed at little or no additional capital cost. The process could be applied to the Burlington STP as well. Water clarity in the harbour would improve by 10%.

Improved agricultural practices which would reduce phosphorus and suspended solids by 50% could lead to a 20% improvement in water clarity. Using conservation tillage practices and improving erosion control could achieve the water quality improvements in time. Since 1980 the Ministry of Agriculture and Food has had a program to help farmers adopt conservation practices.

Water clarity could be improved by an average of 40 centimeters, increasing available fish habitat to 92 hectares as a result of these above improvements. If the proposed habitat construction projects are carried out, these improvements to water clarity could provide approximately 120 hectares of habitat.

Use of sand filters and dual point chemical treatment to control phosphorus will improve water clarity a further 60 centimeters, as well as increasing oxygen levels. The habitat improvements, such as artificial reefs and renewed plant growth, will add to nearshore water clarity. In Cootes Paradise, habitat construction could reduce solids concentrations to 25 milligrams per litre or less.

I.3.4 Oxygen Concentrations

Oxygen levels in the deep water are reduced by bacterial action that converts ammonia to nitrate, and by decaying algae.

Reductions in ammonia loadings could ensure that minimum deep water oxygen concentrations do not fall below 1.5 milligrams

per litre. The phosphorus and silt discharge controls, which will improve water clarity, will also increase the minimum deep water oxygen concentration by another 1.5 milligrams per litre.

If the improved chemical treatment does not adequately control phosphorus, sand filters with dual point chemical treatments at the Hamilton and Burlington STPs could be used. The filters would also improve offshore water clarity by an additional 60 centimeters. Sand filters and dual point chemical treatments would cost \$57 million, with an annual maintenance cost of \$170,000.

Several options for direct treatment of the harbour such as oxygen injection and harbour water circulation have been identified. These could be used to increase oxygen levels until other remedial measures are effective.

1.3.5 Contaminants

The Municipal-Industrial Strategy for Abatement (MISA) program will regulate persistent toxic substances from municipal and industrial sources, based on best available technology (BAT).

Environment Canada and Environment Ontario are currently developing biologically-based sediment quality guidelines. The new guidelines should be in draft form by late 1988, and will update the existing guidelines for open water disposal of dredged material. The purpose of the new guidelines is to help identify sediments which have an unacceptable level of contamination and which may require remedial action. These guidelines will be used to evaluate sediments throughout the Great Lakes.

The RAP writing team is presently unable to determine, to what degree fish tumours and the tissue burden of contaminants in fish are related to contaminated sediments.

The following course of action is recommended:

- a) map areas of highest concentration and toxicity;
- b) determine if biological effects are due to contaminants in the sediments; and
- c) assess alternatives to dredging and confined disposal such as chemical treatment or capping and sealing of the sediments.

I.3.6 Wildlife Habitat

I.3.6.1 Wetlands

Cootes Paradise and the Grindstone Creek delta provide some of the best opportunities for achieving wetland restoration. This is due to the degree of protection from human disturbance and urban development, and the existence of relatively uncontaminated sediments. Access and amenities for wildlife appreciation already exist.

A method of marsh rehabilitation that has been used successfully elsewhere, involves the construction of dikes to close off suitable areas. The Royal Botanical Gardens has sought expertise from Ducks Unlimited to implement such a scheme.

Through the use of pumps, the water level can be manipulated inside the diked areas, regardless of the lake levels. The dikes will also keep out carp and reduce wind resuspension of bottom sediments. The dikes would cost an estimated \$750,000.

A mud flat area for shore birds could be created by placing a berm across the outlet of the West Pond of Cootes Paradise, if the Dundas STP effluent is diverted. Flooding during the summer would limit plants from encroaching on the site, but spring and fall drawdowns through pumping will expose the mud flats, and allow shorebirds to use the area. Exposing the mud flats is especially important during spring migration when the shorebird habitat is restricted.

I.3.6.2 Colonial Waterbirds

A new site for water birds which nest in colonies could be developed in the harbour to accommodate the species currently nesting at the east end dredged spoils area. It is desirable to maintain existing populations, with the exception of the Ring-billed Gulls, which need to be limited to 5000 pairs. Ring-billed Gulls attract other colonial waterbirds such as Caspian Terns, but a one hectare area should be sufficient to accommodate several bird species, while controlling the number of Ring-billed Gulls. This area could be created by enlarging the two Hydro Islands to 0.5 hectares each. How much this option will cost has not been determined.

I.3.6.3 Clean Habitat for Wildlife

Waterbirds will continue to utilize Windermere Basin because it is shallow, the water is ice free in the winter and there is an abundance of food. The dredging project for Windermere Basin is planned to start in 1988 which will remove the contaminated sediments. The project will cost \$4.5 million.

I.3.7 Swimming

If swimming is desired there are three areas which could be considered for building swimming facilities:

- * the former Lax property in the west end of the harbour;
- * the waterfront area adjoining LaSalle Park on the north shore, and;
- * the northeast portion of the harbour adjacent to the Canada Centre for Inland Waters in Burlington.

It is evident that the goal of swimming in the harbour can only be reached if:

- * water clarity is improved by reducing solid and phosphorus loadings from all sources;
- * any bacteriological problem in shoreline areas is resolved;
- * the legal constraints are removed, and;
- * access to swimming areas is provided.

In order to improve water clarity and maintain safe bacterial levels, the CSOs near swimming areas must be controlled. Good solids controls must be maintained at the sewage treatment plants in order to obtain efficient disinfection.

I.4 CURRENT RESEARCH

The Remedial Action Plan should be viewed as an evolving process. As the goals, problems and options for the harbour are discussed among the scientists, stakeholders and the public they become clearer and more focused. The completed RAP will contain an implementation schedule for restoring beneficial uses.

Some options can be implemented now. However, there are a number of problems which are not fully understood and for which solutions have not been found. The RAP writing team and other scientists from the participating agencies are continuing to investigate these problems and their influence on water quality. In particular, remedial measures for contaminated sediments cannot be selected until further studies are completed. In addition some measures are experimental, and should be tested on a pilot scale before they can be considered as viable options for Hamilton Harbour.

Projects planned for 1988 include:

- A. In order to study habitat preferences and the ability of pike to survive, last year's successful program to introduce pike into the harbour will be expanded in 1988. The results of this study will more clearly define how habitat can be improved.
- B. Several studies are planned to increase the understanding of the effect of contaminants in the sediments on plant and animal life. Studies will look at the extent of contaminants in the sediments, the release of contaminants to the water, the effect on plant and animal life and bioaccumulation in the food chain.
- C. Studies of land uses, mapping erosion potential and monitoring creeks will provide information on the sources of silt and suspended solids to the harbour. The results will help to select appropriate actions to reduce erosion and improve water clarity.
- D. Additional measurements of flows within the harbour and between the harbour and Lake Ontario will be used to more accurately predict what further loading reductions are required.
- E. Pilot studies to improve existing processes for removing phosphorus and ammonia from municipal discharges are underway.
- F. More detailed water quality surveys are being undertaken so that a means for measuring the success of remedial actions can be established.

Discussion and written comments on the goals, problems and options is encouraged. These discussions and the results of current research will be reflected in the next discussion paper where the preferred options will be identified. Opportunities for discussion are planned. Please send written comments to:

The Ontario Ministry of the Environment
Ellen Fairclough Building
119 King Street West, P.O. Box 2112, 12th Floor
Hamilton, Ontario L8N 3Z9

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II INTRODUCTION

II.1 HAMILTON HARBOUR: AN "AREA OF CONCERN"

The Great Lakes Water Quality Board, the principal advisor to the International Joint Commission (IJC) on Great Lakes water quality issues, has identified 42 "Areas of Concern" in the Great Lakes Basin. Despite considerable progress over the past decade, problems remain in certain areas where the IJC or other jurisdictional standards for water sediment and biota are exceeded and where additional remedial measures are necessary to restore beneficial uses or to meet these standards.

Hamilton Harbour has been designated as an Area of Concern. In their 1985 report, the Water Quality Board outlined their reasons for so designating Hamilton Harbour. The assessment was provided by the Ontario Ministry of Environment. It is this set of problems that the Remedial Action Plan must first address.

IJC Water Quality Board Assessment HAMILTON HARBOUR (Ontario) NATURE OF PROBLEM June 1985

<u>Types of Problems</u>	<u>Sources</u>
Conventional Pollutants	Municipal Point Sources
Heavy Metals	Industrial Point Sources
Toxic Organics in Fish	Urban Non-point
Contaminated Sediments	Combined Sewer Overflows
Eutrophication	In-Place Pollutants
Fish Consumption Advisories	
Aesthetics	

Municipal and industrial discharges, urban drainage, sediments, and algal decay increase oxygen demand. This oxygen demand depresses hypolimnetic dissolved oxygen levels, especially in the summer. This, in turn, limits the suitability of the deeper part of the Harbour as a fish habitat.

Aesthetic quality is diminished by poor water clarity and colour, as a result of high levels of suspended solids, chlorophyll, and dissolved organics, thereby deterring broader recreational use of the Harbour.

Significant levels of nutrients, several heavy metals, and PCBs have been detected in the surface sediments from several portions of Hamilton Harbour.

Water quality objectives are exceeded for total dissolved solids, zinc, ammonia, and phosphorus. Iron, cyanide, and phenolics also exceed water quality objectives on occasion, especially adjacent to the steel mills on the south shore.

Levels of trace organics (PCB, PAH), and phenols in fish are under investigation.

II.2 THE RAP PROCESS

Underlying this assessment of the Harbour by the Water Quality Board are assumptions about the use of the Harbour. The Water Quality Board decided that to provide an ecological perspective, it would consider environmental quality data for sediment and biota as well as for water. It was also decided to evaluate these areas with uniform criteria. The basic philosophy is to protect the waters for the most sensitive use.

In the past, decisions were not made on what uses would or would not be supported. The view is now held, that a broader consensus is required on the part of the public. One purpose of the public consultation process is to receive input on desired uses.

The fact that a formal process for developing an Action Plan has just recently been initiated (June, 1986) does not imply that nothing has been done in the past to control pollution in the Harbour. Industry and municipal governments have spent approximately \$300 million on pollution abatement problems. By 1989 the major industries discharging to the Harbour will be meeting all the requirements of the current Ontario Ministry control orders.

Now there is a need to consider what measures have to be taken to restore beneficial uses - uses which are still impaired in spite of existing effluent controls. These existing effluent standards may not be adequate to protect the Harbour from total loadings of nutrients and chemicals. Nor does current effluent standards address historical deposits of contaminants in the Harbour.

There are a number of recent reports on water quality in the Harbour that serve as the basis for the Writing Team analysis. The analysis has been extended beyond the Harbour itself to include Cootes Paradise, as there are links to both water quality and habitat development for fish and wildlife.

There are, however, some difficulties in using only the existing information to quantify the impact of some of the major remedial projects that have been considered. For this reason the Writing Team have also drawn upon recent unpublished work and have identified the need for additional information, which will be reflected in our recommendations for work in the future.

This need for further information means that, in some instances, this version of the Plan can only identify decision points in the future when information is available and when alternative strategies to correct a problem can be better assessed. It also means that it will be necessary to carefully monitor the response of the Harbour to remedial actions. In

order to achieve a healthy, edible, self-sustaining warm-water fishery, some aspects of the remedial action may have to be considered as experimental.

Hamilton Harbour is not alone in this regard. There are issues common to most of the "Areas of Concern", particularly the problem associated with historical legacies such as contaminated sediments. For these cases, cooperative action will help develop the knowledge necessary to improve our confidence in the selection of appropriate remedial actions.

II.2.1 The Role Of The Writing Team

The Writing Team for the Hamilton Harbour Remedial Action Plan (RAP) has been asked by the Canada/Ontario Review Board to address the problems identified by the Water Quality Board of the International Joint Commission and the goals specified by the public. The Plan is to be prepared by the Writing Team in consultation with the public and the Stakeholders. The Plan, in its final form, is to include an analysis of the existing conditions, an Action Plan to meet specific objectives, including dates and estimated costs. Finally, the Plan must include the design of a monitoring system to ensure that the Action Plan and the results expected are proceeding on schedule.

Several recent publications have been used extensively by the Writing Team. These reports have provided the background on the environmental conditions. Recommendations contained in the Hamilton Harbour Technical Summary (1985) for additional research has led to work on organic contaminants, fisheries and re-aeration technology. Some of these studies have not reached the stage of published reports, but the Writing Team has had access to these investigators and their work in developing an approach to the Action Plan.

Our knowledge of the Harbour and of Cootes Paradise continues to grow. Much of the new information coming forward is targeted specifically on questions raised in the development of an Action Plan. The Writing Team will need to regularly consult and incorporate these new data into the Plan as it progresses.

The Writing Team has also been helped extensively by other staff of the organizations represented on the team. Their assistance is gratefully acknowledged.

II.2.2 Public Consultation

Public consultation is an important element of the process and serves a variety of purposes. It is needed for refinement of the goals and timetables for water quality and ecosystem improvements. As well, it provides a forum for discussion of cross-jurisdictional issues and develop heightened awareness of the overall program.

Two public consultation processes have been employed. Public meetings for the general population of the watershed are open sessions designed to provide the most recent information on the Remedial Action Plan, and to permit formal presentation of briefs from interested groups. Citizens are also asked to submit their views at the meetings or in writing. These briefs and comments have been considered by the Writing Team and the "Stakeholder Group".

The second process has been to establish a "Stakeholder Group" made up of agencies, organizations, institutions, government departments, industries and private citizen groups who make use of, who wish to make use of, or in some manner have jurisdiction over the use of Harbour water. Some 60 potential Stakeholders were interviewed individually, and eventually 49 have come to form the group.

Through a 2-day workshop in July, 1986, and through subsequent meetings, the Stakeholder Group developed a Stakeholders' Interim Report which summarizes their proposals. This report was submitted to the Ministers of the Environment for Canada and Ontario in September 1986, and forms a basic point of reference for the Writing Team.

The development and updating of the Remedial Action Plan will require continuing consultation. The Stakeholder Group has collectively expressed the wish to be a forum for review of matters having a bearing on the remedial actions proposed for the Harbour, both during and after the Plan is established.

II.2.2.1 The Interim Report of the Stakeholder

The Interim Report of the Stakeholders is a detailed analysis of the present or possible beneficial uses for the Harbour. It describes five principles for development of the Remedial Action Plan as the principles of the ecosystem approach, human health, public acceptance, and aesthetics. In subsequent discussions January 1987, the Stakeholders reaffirmed the principles and added the principle of zero discharge of persistent toxic substances.

The Stakeholders' Interim Report also contains recommendations and general remedial actions for two groups of goals. Goals and actions to permit the current defined uses, included: recreational boating, water sports, shipping and navigation, industrial uses, and waste water receiving body.

Goals and recommendations were identified for uses that are not presently available to any substantial degree. These include: fisheries, wildlife appreciation, swimming, and educational resource.

The reader is encouraged to consult the full report of the Stakeholders. The goals developed by the Stakeholders are included in Chapter III.

The Writing Team is considering this comprehensive list of beneficial uses in the context of the IJC goals for water quality improvement.

II.3 FUTURE OF THE RAP

The document currently contains:

- (a) a description of the existing environment and summary of problems,
- (b) a summary of impaired beneficial uses,
- (c) a description of the causes of the problems, and
- (d) a description of remedial actions proposed to resolve the problems.

It does not yet identify jurisdiction and agencies responsible for implementing and regulating remedial measures, nor does it contain a schedule for their implementation and completion. The final Plan will also need to describe a process for maintaining implementation of remedial programs and should include a description of a process for tracking the effectiveness of remedial actions.

The Agencies and Stakeholders must review the options and recommend preferred options. The public will also be given an opportunity to review the RAP Analysis of Options. During the summer a final document detailing the preferred options will be drafted and reviewed and submitted to the International Joint Commission for review.

III GOALS AND OBJECTIVES FOR HARBOUR RESTORATION

III.1 BACKGROUND

The International Joint Commission (IJC), and its Water Quality Board have historically expressed a strong commitment to involving the public, and affected groups and organizations (Stakeholders), in the development of water quality enhancement strategies. In the preparation of remedial action plans, the IJC has requested public involvement throughout the process, with a view to developing plans which are accepted by the Community. Community commitment is essential as responsibility for remedial actions lies primarily with local agencies, industries - hence, the taxpayer.

The Hamilton Harbour watershed supports a population in excess of 1/2 million. The Harbour has played a vital role in the area's development and because of this, watershed residents and businesses are very aware and interested in the Harbour's future. For decades, local governments and industries have been committed to restoration of the Harbour for beneficial uses.

In developing remedial actions for the Harbour, it was important to collect the views and opinions of Stakeholders and the general public to determine the community's desired use goals for the Harbour. During the research and data collection phases in the RAP's development (1985 - 1987) Environment Canada and Ontario Ministry of the Environment launched a broad based public involvement program to help the RAP Writing Team plan remedial measures and future controls needed to restore acceptable water quality in Hamilton Harbour. Once these goals were identified, the 49-member Stakeholder group reviewed the Writing Team's approach to remedial actions, costs and implementation framework.

The following approach to water quality enhancement is reported in "The Stakeholders' Interim Report (September 8, 1986). Rationales used for the setting of goals is explained more fully in that Report.

III.2 GENERAL PRINCIPLES AND APPROACHES

The Stakeholders' Interim Report detailed a general approach to the development of the Remedial Action Plan. The goals and assumptions included in their report were previously reviewed with the public at a meeting held in July, 1986. Further insight was gained through the public meeting held in March, 1987.

In December, 1986, Stakeholders were requested to provide their constituent group responses to the September Interim report. As well, information provided by the Writing Team on the costs and timing necessary to achieve the Stakeholders' September

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goals was provided. When reviewed in the context of individual stakeholder goals, the views of their constituents and in light of information presented by the Writing Team on the feasibility of certain goals and principles, the Stakeholders Group adopted two sets of overriding goals, or primary and secondary principles. These principles are expected to form the backdrop to the Remedial Action Plan.

III.2.1 Primary Principles

III.2.1.1 The Ecosystem Principle

The Interim Report (September, 1986) discusses the ecosystem principle in some detail. However, when viewed in the context of their constituents' responses, and in light of the unanimity of the group on this issue, Stakeholders strengthened their original principle as follows:

"The eight use goals that collectively are necessary for the rehabilitation of Hamilton Harbour, within the context of an ecosystem approach, that encompasses social, economic and environmental issues. Broadly viewed, these goals can be grouped as Economic (Goals 3,4, and 5) and Environmental (Goals 1,2,6,7, and 8)".

And,

"Economic, social and environmental goals must be viewed in an integrated manner, that not one of the three can or should take precedence over another".

III.2.1.2 Zero Discharge

As a sub-set to the ecosystem principle, the issue of zero discharge was discussed at length. The Stakeholders agreed that while any statement on zero-discharge should be consistent with the Ontario Municipal and Industrial Strategy for Abatement (MISA) definitions, that zero discharge is a philosophy and not a standard. Therefore, the Stakeholders resolved in January that:

"The philosophy be adopted whereas control of inputs of persistent toxic substances shall be zero discharge, and therefore, the discharge of any or all persistent toxic substances be virtually eliminated".

III.2.2 Secondary Principles

Within the Ecosystem approach several secondary principles were adopted by the Stakeholders as a group.

III.2.2.1 Human Health

Potential human health risks are associated with contaminated areas of water. In Hamilton's case, the outflow of contaminated Harbour plumes into Lake Ontario may impact on the

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drinking water supply in Hamilton and Burlington. The Stakeholders therefore recommended:

"THAT the water quality in Hamilton Harbour's drainage basin be improved to ensure continued human health and well-being. And

THAT through an ecosystem approach, the water quality be improved to support a multiplicity of uses, both in the short and the long term".

III.2.2.2 Public Acceptance and Support

In order to achieve public acceptance and support for remedial actions in Hamilton Harbour, which may be extremely costly from a purely economic standpoint, the Stakeholders held the view that the principles of public access and aesthetic improvements are essential to the successful implementation of the RAP. The Stakeholders recommended the final Remedial Action Plan, should include:

"A shoreline management strategy, which would integrate, in a comprehensive fashion, the following four concerns:

- 1) Visual Access
- 2) Major and minor nodes and areas of physical access
- 3) Fish and Wildlife Habitat
- 4) Existing industrial, residential and recreational land uses".

"Underscoring this strategy, is the assumption that:

Public access is an important factor in achieving public awareness and support for Hamilton Harbour remedial actions;

That public support for these actions will result in water quality improvements, leading to community benefits; and,

That increased access is a key to achieving remedial actions and should become part of the overall solution whilst recognizing that access is a local authority concern".

III.2.2.3 Aesthetics

Shoreline and water aesthetic improvements are important in the public's perception of the Harbour.

The Stakeholders agreed that aesthetic improvements on a Harbour-wide basis, provide the public with a basis for genuine belief that water quality can be improved.

AMENDMENT

REMEDIAL ACTION PLAN FOR HAMILTON HARBOUR

"GOALS, PROBLEMS AND OPTIONS" March, 1988

1. Page 26: Substitute III.2.2.3 Aesthetics with the following:

Recognizing the importance of ensuring broadened opportunities for the general public to enjoy the benefits of an improved harbour resource on a continuing basis:

III.2.2.3 Access (Physical and Visual)

It is the position of the Stakeholders' Group that significant improvement is required in terms both of quantity and quality, to the opportunities and locations for physical and visual access to the Hamilton Harbour.

III.2.2.4 Land Use

That the issue of the character and appropriateness of the land uses situated adjacent and in close proximity to the Harbour is of major consequence and must be addressed, if a successful and comprehensive plan for the remediation of the Hamilton Harbour is to be achieved.

III.2.2.5 Aesthetics

Shoreline and water aesthetics improvements are important in the public's perception of the Harbour.

The Stakeholders agreed that aesthetic improvements on a Harbour-wide basis, provide the public with a basis for the genuine belief that water quality can be improved.

Amended at Stakeholders' Group meeting dated April 27, 1988

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Stakeholders provided the governments with an in depth view of Harbour Water Impacts on Lake Ontario; the Windermere Basin; Restricted Uses and Actions: Shoreline Filling and Waste Water Receiving Body, as well as details on current and preferred water use goals. These discussions are contained in the Stakeholders' Interim Report, and are not duplicated here. However, it would be beneficial that the reader review these sections in order to gain a better understanding of the following discussions.

III.3 WATER QUALITY ENHANCEMENT

A number of issues technically outside of the RAP's terms of reference were considered since they are important when implementing the Ecosystem approach.

III.3.1 Impacts on Lake Ontario

Drinking water intake pipes for Burlington and Hamilton are located in Lake Ontario, therefore, water quality in the Harbour does not need to support drinking as a use.

However, as it is a possibility that Harbour water quality may detrimentally effect Lake Ontario, the issue was considered to be serious enough to be seen as an overriding, general goal, which all Harbour-wide uses and remedies should address.

STAKEHOLDERS'

GOAL: "To remove the potential negative impact on Lake Ontario, from Hamilton Harbour's water quality; with particular attention to areas of nearshore public uses and drinking water intake pipes for the Cities of Hamilton and Burlington".

III.3.2 Windermere Basin

In 1986 a preferred option was selected for the clean up of Windermere Basin. There exists a strong commitment from the various levels of government to proceed to implementation. In light of the progress of the Remedial Action Plan, the Stakeholders recommended:

"THAT the Windermere Basin study (1986) and recommended remedial actions be considered separately from and proceed in advance of the overall Harbour RAP, providing that the Ontario and Federal Environment Ministers ensure full public consultation and hearing on the alternatives".

III.4 RESTRICTED USE

In order to achieve the overall objectives for Hamilton Harbour's water quality in such a way as to provide an enhanced ecosystem, certain water uses and actions needed to be

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restricted, in that their continuation, in general terms, would negatively affect remedial actions designed to improve water quality.

III.4.1 Shoreline Filling

Shoreline filling could detrimentally affect water quality but could also benefit the social, economic and environmental quality of the Harbour. The Stakeholders suggested for future consideration;

THAT any filling for environmental or access enhancement purposes should:

- meet the objectives established in the RAP;
- contain fill of an acceptable quality to meet provincial guidelines;
- be subject to environmental assessment.

It is noted that fill, for purposes other than environmental and access enhancement, will require separate consideration.

III.4.2 Waste Water Receiving Body

In order to achieve desired uses, its current use as a waste water receiving body in the total Harbour should be restricted to certain areas or zones of the Harbour. For example, sewage treatment plant outfalls would not be acceptable in a proposed swimming area; where habitat may be damaged; or where body contact sports are proposed.

III.5 WATER USE GOALS

III.5.1 Introduction

Within the overall context of the ecosystem approach, and the general water quality goals established earlier, and taking into account restricted uses and peripheral issues, 11 current and desired uses in the Harbour were identified. A number of these uses are, to some degree, currently in place.

III.5.2 Enhancement of Existing Uses

III.5.2.1 Recreational Boating

Recreational boating is one of the preferred uses of the Harbour. Since increased boating may affect water quality, the Stakeholders considered tighter control of motor boats and enforcement of regulations be a prerequisite.

STAKEHOLDERS'

GOAL: Immediate action should be taken to improve water quality for recreational boating, on a continuing basis, for the total Harbour.

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III.5.2.2 Water Sports

Activities in this category include: windsurfing, kayaking, ice boating, or any other activities which involve the human body being in direct contact with the Harbour water.

STAKEHOLDERS'

GOAL: THAT, on an area specific basis, water quality should be improved to permit increased use of the Harbour for water sports on a continuing basis.

III.5.2.3 Shipping and Navigation

Shipping and navigation uses are seen as an essential ongoing use of the Harbour's surface water. Activities integral to the continuation of this use include occasional dredging to maintain navigational channels.

STAKEHOLDERS'

GOAL: Shipping and navigation uses should continue and be contained in certain areas of the Harbour, with a view to reducing negative water quality impacts.

III.5.2.4 Industrial Uses

Water quality for industrial uses was reviewed from two perspectives - the first relating to quality sufficient to supply industry with its water requirements; the second, the quality of the water re-entering the Harbour, subsequent to its use.

STAKEHOLDERS'

GOAL #1: THAT the quality of the Harbour water should be improved to permit continuation of industrial uses.

STAKEHOLDERS'

GOAL #2: THAT industrial water uses should continue in certain areas of the Harbour, and that effluent discharges should meet Ministry of the Environment guidelines (MISA).

III.5.2.5 Waste Water Receiving Body

The Stakeholders recognized that waste water inputs will continue to enter the Harbour.

STAKEHOLDERS'

GOAL #1: THAT the Harbour's current status as a waste water receiving body be changed, so that it becomes a recipient of acceptable effluent, in specific areas; and

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STAKEHOLDERS'

GOAL #2: THAT a loadings-target approach be established for point and non-point pollutant sources, and linked to all other uses to ensure effluent quality does not impede other uses.

III.5.3 Enhancement of Future Uses

III.5.3.1 Fisheries

Historically, the Harbour has supported a generous and diverse fishery. Industrialization, other developments and miscellaneous other uses have despoiled or destroyed habitats and spawning areas. However, a limited warm water fishery has survived and is expanding with improvements in water quality. While provincial consumption guidelines are not exceeded, tumour growths on certain species are widespread in the Harbour (and in other Great Lakes areas). This situation has led to general public antipathy regarding sport fish consumption. Public perception of high water and sediment contaminant levels has recently been confused and intensified by the death and disappearance of a number of Pekin ducks which were placed, for test, in the Windermere Basin.

Fisheries and wildlife coexist in the same warm water and littoral marsh habitats. Sufficient marsh-habitat restoration to ensure an improved reproducing, self-sustaining warm water fishery, would also encourage increases in wildlife habitats. Improved wildlife habitats further lead to improved aesthetics and wildlife appreciation.

STAKEHOLDERS'

GOAL: Water quality and fish habitat should be improved to permit an edible, naturally reproducing fishery for warm species. Water and habitat conditions in Hamilton Harbour should not limit natural reproduction and the edibility of cold water species.

III.5.3.2 Wildlife Appreciation and Habitat Protection

Habitat and natural protection areas, in the short term, would contribute to a greater appreciation of wildlife and the Harbour itself. This is another example where enhancement would build public acceptance of improved water quality, leading to public support for financing of remedial measures.

STAKEHOLDERS'

GOAL: Water quality improvements should be made to permit an enhanced wildlife habitat on a Harbour-wide basis.

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III.5.3.3 Swimming

The Stakeholders agreed that swimming is a desirable goal for specific, restricted areas of the Harbour (e.g. West end and North Shore).

STAKEHOLDERS'

GOAL #1: Providing that water quality meets appropriate health standards in the west end to support swimming as a use, water quality be enhanced to permit swimming, in the short term; and

STAKEHOLDERS'

GOAL #2: In the event that fecal coliform counts exceed water quality objectives for human contact, consideration should be given to using disinfectants and suitable membrane barriers to permit swimming, in the short term; and

STAKEHOLDERS'

GOAL #3: Hamilton Harbour water quality should be improved so that it (a) provides for swimming in certain areas of the Harbour over the long term; and (b) has no impact on water quality for swimming in nearshore Lake Ontario.

III.5.3.4 Educational Resources

Hamilton Harbour, its watershed, ecosystem, and multiple uses, is seen as an educational resource for students of all ages and community populations. The Stakeholders recommended:

- 1) "That educators be represented as a stakeholder group; and
- 2) That MOE and DOE should work separately with formal and informal education groups to promote the Harbour as an educational resource; and
- 3) Educational programs be developed to change public perception of the current condition of the Harbour in support of efforts made by Stakeholders, towards remedial actions".

III.6 PLAN DEVELOPMENT AND IMPLEMENTATION

The Stakeholders agreed and recommended:

- 1) That the Stakeholders group continue to meet until the plan is completed; and
- 2) That the group will review its role at the time of plan completion; and

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3) That it requests funding from the Ministry of the Environment and the Department of the Environment to continue its deliberations until the plan has been submitted to the IJC.

When reviewing its future role, during its agreed tenure, the Stakeholder group decided that the following activities could be considered appropriate:

- 1) address implications for official plans;
- 2) review of water quality enhancement plans in progress, spearheaded by individual stakeholder groups to identify the implications of RAP goals on these plans;
- 3) identify long term RAP goals, and steps needed to achieve these goals;
- 4) identify the appropriate technical, political, economic sequence for achieving RAP goals;
- 5) identify available funds and promote agency commitment for remedial actions;
- 6) involve and hear from the general public relating to:
 - stakeholder goals and actions;
 - RAP goals and actions.

III.7 INCORPORATION OF STAKEHOLDERS' GOALS INTO THE RAP

III.7.1 Primary Principles

The Ecosystem principle and zero discharge philosophy are enshrined in the Great Lakes Water Quality Agreement of 1987 between Canada and the USA. As such, these two principles must be the touchstone of all RAP's. The question then remains as to how to realize these principles in concrete terms.

The ecosystem principle embodies a more holistic way to plan, research and manage the Harbour, and was embraced by the Stakeholders. The intent of the Goals, Problems and Options Report is to provide as much information (and knowledge) as possible about the Harbour in its social, economic and environmental aspects. The Writing Team members found a lack of information or understanding of aggregate social valuing and have, perhaps, fallen prey to documenting each compartment of knowledge that each knows best (natural sciences, engineering, etc.).

Inevitably, the complexity of the 'system' in its economic, social and environmental dimensions is an obstacle to easy comprehension. Thus the approach the Writing Team has taken is to try to present the options in more comprehensible 'compartments' and then draw together the connections where there are significant interactions in order to view the issues 'whole'.

One obstacle to realizing this principle is the lack of a preventative approach (Christie et al, 1986). The Goals, problems and Options Report does not address in sufficient detail measures that might be taken to provide the people and the wildlife that share this area with a bit of a buffer from future surprises. The report points out the problems of choosing chemical composition target concentrations (as opposed to loading targets) or even choosing to address only a certain list of chemicals. There is considerable potential for minimizing the use of chemicals known to be harmful and for finding softer alternatives (less toxic chemicals, more recycling, more efficient energy use, etc.). There is a need to give more consideration to the application of existing knowledge to achieve better compatibility of human society within its natural setting.

The zero discharge philosophy needs to be addressed in the Remedial Action Plan. The Municipal and Industrial Strategy for Abatement (MISA) is based on this philosophy. There is periodical debate between those who say zero discharge of persistent toxic chemicals is necessary and those who say that it is impossible. For example current discharges of PAHs to Hamilton Harbour are about 1.5 kg/day. Compared to discharges of approximately 1000 kg/day, a decade or more ago, this current discharge looks pretty small. It is estimated that the current discharge could probably meet both water quality and sediment quality (for new sediments) objectives. However, further action is being taken. Implementation of practical measures to reduce PAH loadings to 0.7 kg/day is already in progress. There are no 'practical' measures to go further at this time, although the research continues. The Writing Team believes this is a practical demonstration of the zero discharge philosophy because it:

- 1) sets a target,
- 2) goes beyond the target where practicable, and
- 3) considers investigation of more creative or more economic ways to achieve even further reductions.

III.7.2 Secondary Principles

Human Health

Remedial measures targeted on point sources to reduce the contaminant concentrations in the east end of Hamilton Harbour will reduce the impact that existing outflows to Lake Ontario may have on the lake beaches or the water supply intakes of Hamilton and Burlington that are in the lake. The variability of water quality in the lake may preclude finding evidence from intake waters that an improvement actually would have taken place. However, the direction of the change is clear.

Diversions within the Harbour (ie transfer of Dundas STP effluent to the Hamilton STP) which alter the point of loading from the west end of Cootes Paradise to the east end of the Harbour would have to take into consideration the effect of

natural treatment by the Harbour. Treatment in this case may have to be equivalent to ensure there would be no effect on Lake Ontario uses. The main concern here is for toxics.

Some care would have to be taken in any action (such as dredging the Burlington Ship Canal) that could enhance flushing of the Harbour by lake water. Such flushing will benefit water quality in the Harbour at the expense of water quality in the Lake near the Canal.

Water quality problems on the lake beaches have been addressed to some extent in the past and have not been found to be due to Harbour effluent. Should such problems require further attention they should not be assumed automatically to be the fault of Harbour effluent, but be assessed for other possible causes.

Of more direct concern is the contaminant content of fish in the Harbour that fishermen might consider eating. The Ontario Sport Fish Consumption guidelines apply to species found in the Harbour. The information available is encouraging and each remedial measure will be carefully considered as to its potential for decreasing these contaminants even further.

Public Acceptance and Support

The technical writing team is making several efforts to communicate the results of their deliberations to the public.

Attention has been paid to the aesthetic aspects of water quality (water clarity and water colour) where they affect conditions near the shore. It turns out that this zone is probably the most difficult to address in a comprehensive way because it is affected not only by general Harbour-wide conditions, but also by such things as creek inflows, wind blown flotsam, and shore processes such as wave action on shore sediments and soils.

Access

The concern for water quality at the point of access is important- whether it be a question of Harbour-wide processes; or whether local activities adversely affect the water quality.

A great deal will depend on the local 'housekeeping' once the overall suspended sediment and phosphorus loadings are reduced. If a particular area is slated for access development, nearby creeks, local fugitive runoff or construction activity, or any nearby combined sewer overflow would be logical places to look for ways to improve water quality locally.

Aesthetics

This principle has a close relation with the previous one insofar as water quality is concerned. Programs identified to

deal with Windermere Basin, the stream erosion, shore erosion and stream contamination will all aid in meeting with the concerns expressed in this principle.

Programs for landscaping and air quality, already planned or under way are documented in this report. The efforts of the Naturalist Club and MOE in promoting the physical clean-up of debris and litter is commendable in this regard.

Better compliance with litter regulations would substantially improve those conditions and more landscaping projects could be considered.

Considerations Relating to Water Quality Enhancement

1) Impacts of Harbour Water on Lake Ontario

The Options considered in this report are designed to reduce loadings at source, with no diversion into the Lake. As such, any improvements in water quality that result from source controls should result in an improvement in the water discharging to the lake.

Since the major sources are at the east end of the Harbour, and the most cost-effective source controls for contaminants is focussed on these major sources, the improvement in discharge to the Lake should be proportionally larger than the benefit to the Harbour as a whole.

2) Windermere Basin

This dredging project is proceeding and an Initial Assessment as called for by EARP is being prepared.

Restricted Uses and Actions

1) Shoreline Filling

This activity takes many forms from efforts by private property owners to protect the shoreline from erosion, to major projects for docks, industrial property or confined disposal facilities for dredged material.

It would appear that its major impact on environmental matters is in terms of its effect on fish and wildlife habitat, assuming that contaminated fill material is properly confined.

Some habitat requirements may be enhanced by the design of the shoreline configuration, and provision of shallow depths and coves. Hence there is a potential to mitigate the impact of development-perhaps even to enhance it. The concepts proposed for enhancing the warm water fishery are examples of such proposals (VI.2).

Current and Preferred Water Use Goals

The Writing Team used the Stakeholders' goals as a basis for assessing current conditions and identifying possible remedial

options for restoration of the Harbour. It was observed that the limitations to achieving the fish, wildlife and swimming goals are common to all the Stakeholders' goals. Options to address 3 goals will also satisfy the water quality requirements to restore the remaining goals. It is for this reason Chapter 6 focuses on the fishery, wildlife and swimming goals.

In addition, however, there are water quality conditions that need attention according to the MOE and IJC objectives, that are not caught up in the goals for these beneficial uses. For this reason there are some additional elements. These include the program for dissolved solids, based on the IJC principle of non-degradation, and, to some degree, the program to address contaminated sediment.

IV THE HAMILTON HARBOUR ECOSYSTEM

IV.1 DESCRIPTION OF AREA

IV.1.1 Geography and Geology

IV.1.1.1 Geographic Description

Hamilton Harbour is located at the west tip of Lake Ontario (Figure 1). A sandbar separates the Harbour from Lake Ontario and exchange with the Lake is accommodated through the Burlington Ship Canal (820m x 88m x 9.5m). The Harbour is triangular in shape with an east-west axis of 8 km and a north-south axis of 5 km. The surface area of Hamilton Harbour is 2150 hectares. With a mean depth of 13 m and a maximum depth of 26 m, the Harbour has a theoretical residence time (ie. volume/inflow) of over 400 days but exchange with Lake Ontario shortens the residence time to an average of only 90 days.

The mouth of the Grindstone Creek, in the northwest sector of the Harbour is an important shallow littoral habitat area. Approximately 380 hectares (17%) within Hamilton Harbour have water depths shallower than 6 meters (the littoral zone) but less than 60 hectares are currently colonized by aquatic vegetation due to various physical stresses and poor water clarity.

The pelagic zone occupies 83% of the area of the water's surface. Due to the morphometry of the Harbour basin, the hypolimnion contains 50% of the total volume of water in the Harbour ($2.8 \times 10^8 \text{ m}^3$). The hypolimnion is significant in the Harbour because during the summer when stratification becomes established, oxygen exchange with the atmosphere is cut off and the oxygen remaining in the hypolimnion is quickly depleted.

At the far west end of Hamilton Harbour is the Desjardin Canal, which leads to Cootes Paradise. Cootes Paradise has an open-water surface area of 250 hectares, a mean depth of 0.7 m, and a hydraulic residence time of several days depending on the season. The long axes of both Cootes Paradise and Hamilton Harbour are oriented northeast-southwest which is also the predominant axis for the prevailing winds.

Windermere Basin, in the southeast corner of Hamilton Harbour, has a surface area of approximately 40 hectares and a mean depth of 0.7 m.

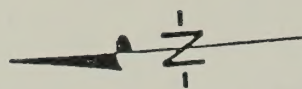
IV.1.1.2 Drainage Basin

The total drainage basin of Hamilton Harbour including Cootes Paradise is 49,400 hectares (Figure 2). Cootes Paradise receives runoff from five sub-watersheds for a total sub-basin area of 26,000 hectares. Spencer Creek, with a total area of 17,000 hectares, is the largest sub-watershed in the Cootes Paradise drainage basin. Red Hill Creek (7,190 ha.), Grindstone Creek, Indian Creek/Rambo Diversion as well as numerous combined sewer water overflows and smaller creeks enter into the Harbour.

Figure 1

HAMILTON HARBOUR SHORELINE

0 1 2 km



LAKE

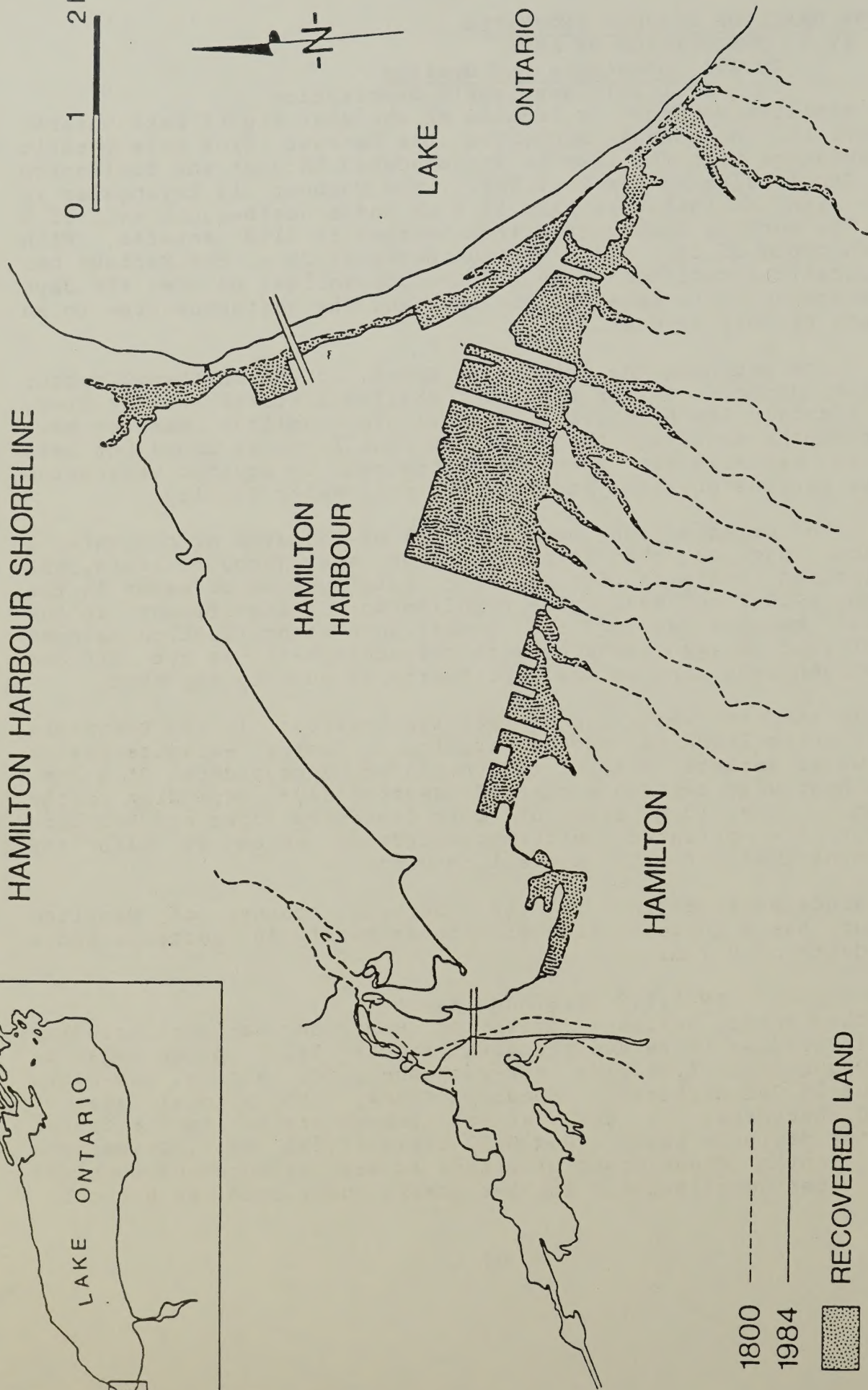
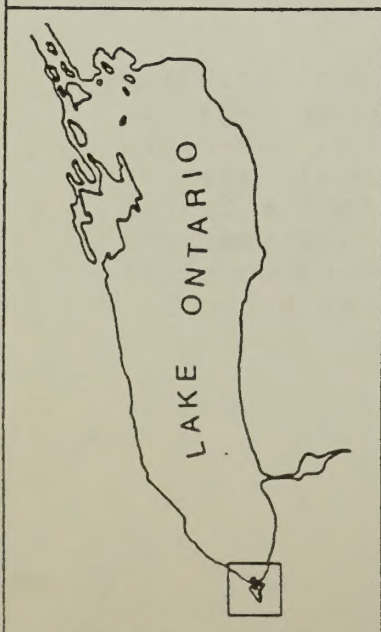
ONTARIO

HAMILTON
HARBOUR

HAMILTON

1800
1984

RECOVERED LAND



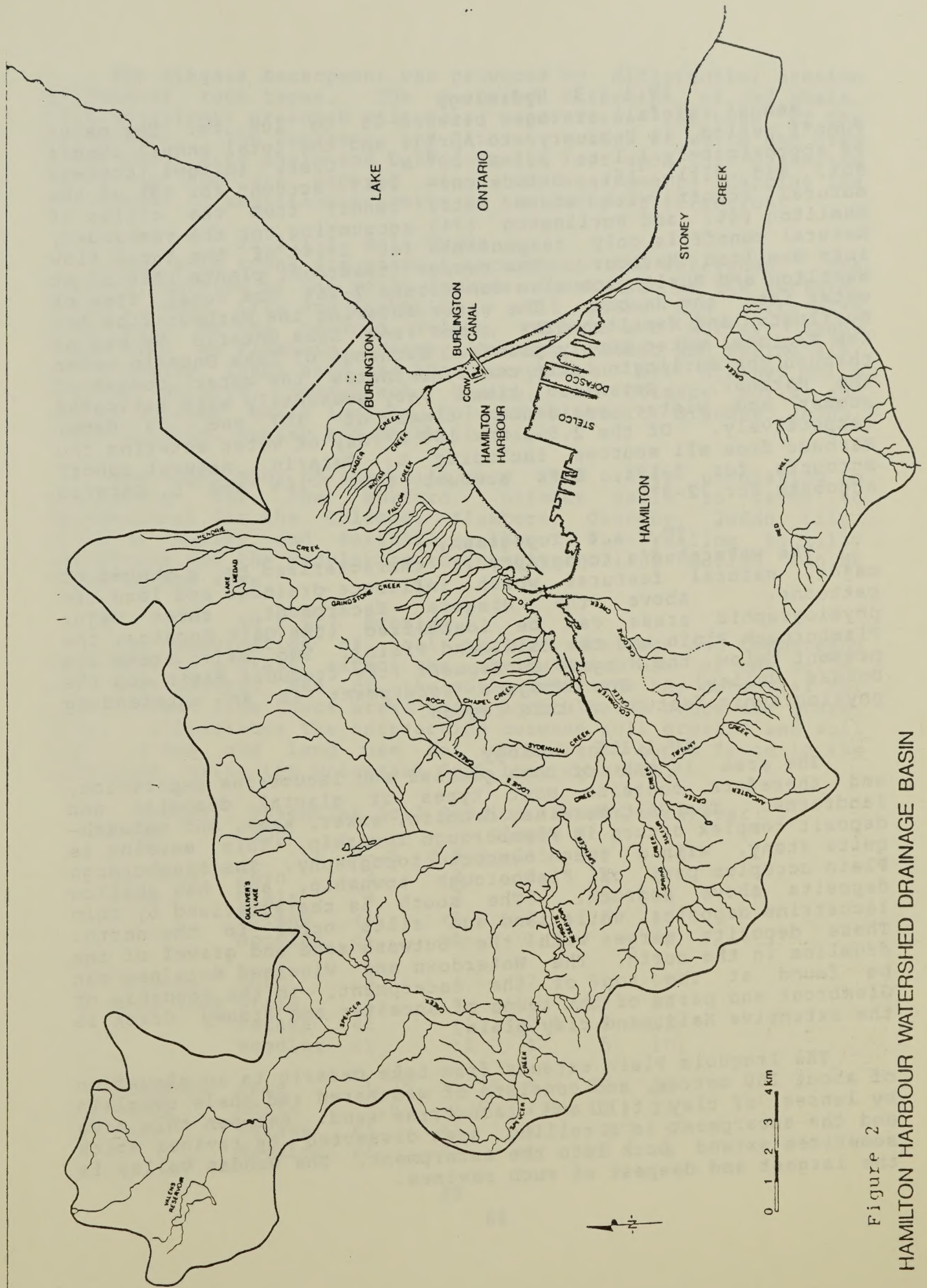


Figure 2
HAMILTON HARBOUR WATERSHED DRAINAGE BASIN

IV.1.1.3 Hydrology

Annual rainfall averages between 65 to 108 cm. The major runoff period is February to April, and the total annual runoff is approximately 1.1 to $2.1 \times 10^8 \text{ m}^3$. Creek inflows (Cootes-60%, Red Hill- 15%, Grindstone- 14%) account for 89% of the natural runoff with storm water runoff from the cities of Hamilton (4%) and Burlington (7%) accounting for the remainder. Natural runoff is only responsible for 2-19% of the total flow into Hamilton Harbour. The sewage treatment plants (STP's) at Hamilton and Burlington also contribute 7-16% the total flow of water into the Harbour. The water entering the Harbour from the Burlington and Hamilton STPs comes from Lake Ontario by way of the Regional water supply plants. Exchange of Lake Ontario water through the Burlington ship canal dominates the water budget of the Harbour. Retention times vary seasonally with estimated summer and winter residence times of 107 and 73 days, respectively. Of the $2.6-3.8 \times 10^6 \text{ m}^3/\text{day}$ of water entering the Harbour from all sources including L. Ontario, natural runoff accounts for 2-19%, STPs account for 7-16% and L. Ontario accounts for 72-87%.

IV.1.1.4 Topography

The watershed's topography is characterized by a number of major, natural features which influence drainage and land use patterns. Above the Niagara Escarpment, three major physiographic areas can be identified (the Galt Moraine, the Flamborough Plain and the Haldimand Plain). Two major areas are present below the Niagara Escarpment (the Iroquois Plain and the Dundas Valley). The Niagara Escarpment is an outstanding physiographic feature of this region.

IV.1.1.5 Geology

The area is one of both glacial and lacustrine deposition, and therefore contains most types of glacial deposits and landforms. The Galt Moraine, drumlin, esker, kame, and outwash-deposit complex occurs in Flamborough Township. This moraine is quite stony, with a rough hummock topography. The Flamborough Plain occupies part of Flamborough township, and has shallow deposits above bedrock. The south is characterized by thin lacustrine deposits, while sand and silts occur in the north. These deposits merge with the outwash sand and gravel of the drumlins in the north. The Waterdown and Vineland Moraines can be found at the top of the escarpment. In the township of Glanbrook and parts of the towns of Ancaster and Stoney Creek is the extensive Haldimand clay plain.

The Iroquois Plain extends from Lake Ontario to an elevation of about 100 metres, and consists of weathered red shale overlain by lenses of clay till and lacustrine sand. Between this area and the escarpment is a rolling area dissected by ravines which sometimes extend back into the escarpment. The Dundas Valley is the largest and deepest of such ravines.

The Niagara Escarpment was produced by differential erosion of several rock types. The Queenston formation of red shale, with occasional greenish siltstone bands forms the base of the escarpment. The Cataract and Clinton groups of white and grey sandstones, grey shale and buff dolomite rest upon this Queenston formation and are exposed along the escarpment. Capping the escarpment is resistant dolomite of the Lockport formation.

IV.1.1.6 Soil Types

Many soil types are present throughout the watershed. The surface textures of the soils include: loams such as the Burford, Guelph, Jeddo, Lily and Parkhill; silt loams and silty clay loams such as the Colwood, Toledo, Lincoln and Morley; sandy loams such as Flamboro, Granby, Grimsby, Jeddo and Springvale; and gravelly loams such as the Donnybrook. Well drained soils include Burford, Donnybrook, Guelph, and Grimsby soils; and poorly drained soils include Colwood, Flamboro, Grandby, Jeddo, Lily, Lincoln, Morley and Parkhill soils.

The topography of the soils vary from gently undulating to undulating for the Burford, Grimsby soils to level to depressional for the Colwood, Flamboro, Grandby, Jeddo, Lily, Lincoln, Morley and Parkhill soils. The rolling to hilly Donnybrook and the undulating to gently rolling Guelph can be found in the area.

IV.1.1.7 Erosion

The combination of soil texture, drainage and topography determine to a great extent the agricultural use of the soils. The agricultural use of the soils determine the potential for soil erosion from those areas where agricultural crops are grown. Table 1 illustrates the interaction between soil erosion and soil type, slope and land use for three soil types found in the watershed, using the Universal Soil Loss equation.

Table 1. Potential Soil Erosion (Tonnes/acre/year)

Soil	Crop	Slopes %				
		0-.5	0.5-2	2-5	5-9	9-15
Burford loam	Corn	3	3	9	24	47
	Grain	3	3	8	23	44
	Forage	<1	<1	2	5	10
	Woodlot	<1	<1	1.5	4	8
Colwood silt loam	Corn	4	4	12	31	59
	Grain	4	4	11	29	55
	Forage	<1	<1	2.5	6	12
	Woodlot	<1	<1	2	5	10
Flamboro sandy loam	Corn	1.75	1.75	5	13	25
	Grain	1.6	1.6	4.5	12	23
	Forage	<1	<1	1	2.7	5
	Woodlot	<1	<1	<1	2	4

Silt loam and the silty clay loam soils can be very susceptible to erosion. Long or short steep slopes possess a high potential for erosion. The conventional cultivation of row crops that result in little soil cover over winter and spring has the potential for increased movement of the soil.

The loss of 3 tonnes/acre of soil is the maximum acceptable level of soil loss since mineral soils are able to develop at about that rate. However, if the loss of soil is greater than 1 tonne/acre from fields adjacent to water courses, water quality may be affected.

When corn and cereal grains are grown with conventional tillage on any slope class there is a potential for erosion losses greater than 3 tonnes/acre with the Burford, Colwood, Donnybrook, Guelph, Jeddo, Lily, Lincoln, Morley, Parkhill and Toledo loam, silt loam, silty clay loam and gravelly loam soils. The erosion potential is reduced to 3 tonnes/acre when forages and woodlots are found on slopes equal to or less than 5%. The potential for erosion is less than 3 tonnes/acre where corn and cereal grains are grown with conventional tillage on slopes up to 2% on Flamboro, Grandby, Grimsby, Jeddo and Springvale sandy loam soils. The potential for erosion is less than 3 tonnes/acre where forages and woodlots are found on slopes less than 5%.

The erosion potential of forages and woodlots on slopes less than 2% is less than 1 tonne/acre with the Burford, Colwood, Donnybrook, Guelph, Jeddo, Lily, Lincoln, Morley, Parkhill and Toledo loam, silt loam and silty clay loam and gravelly loam soils. The erosion potential of forages and woodlots on slopes less than 5% is less than 1 tonne/acre with the Flamboro, Grandby, Jeddo and Springvale sandy loam soils.

The use of conservation tillage techniques including cross slope cultivation and planting, residue management using conservation tillage equipment, crop rotation with forage grasses and legumes, cover crops and buffers may reduce the erosion potential to that which is acceptable for agronomic and water quality reasons.

Erosion of soils, transportation, sedimentation and resuspension has resulted in an average sedimentation rate in the east end of Cootes Paradise of 1 cm/year. Suspended solids concentrations as high as 2,300 mg/l were observed in a 1987 runoff event in Spencer Creek. Urban construction practices in Dundas are felt to be the major contributor, since the watershed above the escarpment has a flood control reservoir which would dampen the impact of rainfall events. Grindstone Creek also has significant erosion events that have resulted in the deposition of clay/silt sediments in the mouth area in Hamilton Harbour. As far back as 1966, erosion was identified as a serious problem in Grindstone Creek. In 1966-67, Grindstone Creek discharged 2,260

tons of suspended solids. When compared to other area creeks and rivers, Grindstone was by far the worst. Grindstone, Spencer and Red Hill Creeks had 87, 42 and 10 tons per year per cfs of suspended solids in 1969, respectively. The following types of erosion were observed in the Grindstone Creek watershed: sheet, rill, gully, channel, in-stream, unstabilized stream banks, urban construction practices, road embankments and excavations. A 1978 survey concluded that the majority of the suspended solids originated in the lower portion of the Grindstone Creek, below the escarpment. Steep slopes combined with relatively impervious clay and shale deposits resulted in the rapid erosion of any exposed soil.

The average annual sedimentation rate in the Harbour has been estimated from limited sediment trap data to be approximately $6.5 \text{ g/m}^2/\text{day}$ (Charlton NWRI unpublished data). The total annual amount settling out over the entire Harbour would be estimated to be approximately $5.2 \times 10^7 \text{ kg}$. Assuming an average surficial sediments' weight of 0.34 g/cc (Nriagu et al., 1983), the sedimentation rate measured in the water column translates to an annual deposition of 0.7 cm/yr . Nriagu et al. (1983) determined a deposition rate of between 0.12 cm/yr and 0.35 cm/yr . Examination of their sediment profiles of trace metals would suggest that the 0.35 cm/yr rate is a good estimate of the deposition rate over the past 30-40 years. A net accumulation rate of 0.3 cm/yr was also determined for the area in Lake Ontario, outside the Burlington Ship Canal (Poulton et al., 1986).

IV.1.1.8 Historical Changes

The current outlet from the Harbour to Lake Ontario was constructed in 1823. Little change in the shoreline of the Harbour occurred until 1853 when a new outlet from Cootes Paradise to the Harbour was constructed for the Desjardin Canal. The old channel was filled in to permit railway construction, leaving Mercer's Glen, Long Pond and Sunfish Pond as the only remnants of the original channel. Little filling has been done on the north shore with the exception of the LaSalle Park Pier and the filling of Brants Pond in the northeast corner. The southwest end of the Harbour was modified by railway construction in the late 1800s. Between 1862 and 1926, industrial and port expansion began filling in the extensive marsh habitat on the south shore. By 1959, the south shore marshes had been filled in and Windermere Basin had been created (Figure 1). By 1976, 22 percent of the open water area in the Harbour was lost, relative to 1926. The most serious loss to the Harbour was the extensive marsh littoral area. The current wetland area is estimated to be less than 50 hectares from an historic maximum of approximately 500 hectares. The loss in marsh littoral area has had a profound impact on the fishery and wildlife.

IV.1.2 Current Land Uses

A land use survey has not been conducted on the complete Hamilton Harbour watershed but one is planned in the immediate future to identify non-point sources of suspended solids. Some general features can, however, be presented (Figure 3).

IV.1.2.1 Urban

Urban centers located in the watershed are Hamilton (360,000), Burlington (120,000), Stoney Creek (25,000), Dundas (20,000) and Ancaster (15,000). Projected population increases for the basin are approximately 10% from the above 1982 population estimates to the turn of the century. Urban growth within the watershed has historically centered on the City of Hamilton. Development has resulted in a nearly continuous urban area surrounding the Harbour. The urban centers are largely below the Niagara Escarpment.

IV.1.2.2 Rural

A few small towns exist above the escarpment. Waterdown is a small town (pop. 4000) above the escarpment which has a 2400 m³/day sewage treatment plant discharging into Grindstone Creek.

IV.1.2.3 Industrial

The Harbour's deep water port supports the largest concentration of heavy industry in Canada. The port and the associated industries are located along the south shore of the Harbour. The major industries are the iron and steel industries. Direct and indirect employment related to the Port facilities is estimated at 30% of the total area employment.

IV.1.2.4 Landfill Sites

Only one operating municipal landfill site is located in the Hamilton Harbour watershed. The site is located in Burlington and the leachate is collected for treatment at the municipal sewage treatment plant.

There are seven closed municipal landfill sites in the watershed. Three of these have leachate collection for treatment at municipal sewage treatment plants (STPs). Five privately operated non-hazardous solid industrial waste sites are located in the watershed. Only one of these sites is receiving putrescible material. Leachate from this site is being collected for treatment at a municipal STP.

Studies have been carried out at all landfill sites and reports are available from the regional MOE office. No detrimental effect on receiving waters is being observed at any of these sites.

The Burlington Landfill site is approximately 29.3 hectares and is scheduled to be closed in 1988. The site is adjacent to Falcon Creek, approximately 3.5 kilometers from Hamilton Harbour.

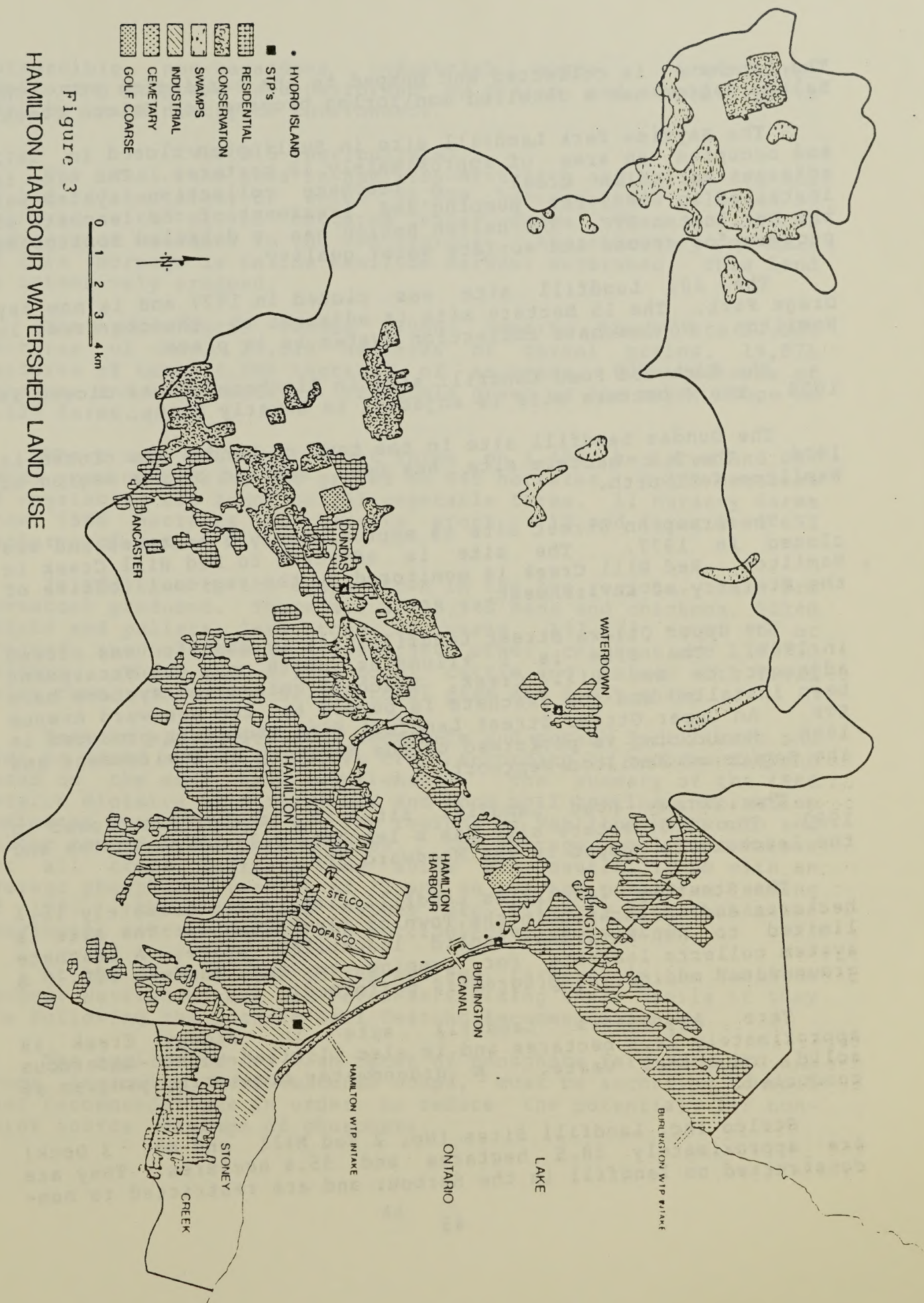


Figure 3
HAMILTON HARBOUR WATERSHED LAND USE

The leachate is collected and pumped to the Burlington STP. The Halton Region has a detailed monitoring program for Falcon Creek.

The Bayview Park Landfill site in Burlington closed in 1972 and occupied an area of approximately 18 hectares. The site is adjacent to Indian Creek. A leachate collection system was installed in 1986 for pumping and treatment of the leachate at the Burlington STP. The Halton Region has a detailed monitoring program for ground and surface water quality.

The 403 Landfill site was closed in 1977 and is now Kay Drage Park. The 15 hectare site is adjacent to Chedoke Creek in Hamilton. No leachate collection system is in place.

The Edgewood Road Landfill site in Flamborough was closed in 1978. The 4 hectare site is adjacent to Beverly Swamp.

The Dundas Landfill site in the town of Dundas was closed in 1976. The 9.4 hectare site has been sampled by the Region of Hamilton-Wentworth.

The Brampton Street Site is approximately 5 hectares and was closed in 1977. The site is adjacent to Red Hill Creek in Hamilton. Red Hill Creek is monitored by the regional office of the Ministry of Environment.

The Upper Ottawa Street Landfill site in Hamilton was closed in 1980. The site is 1 kilometer north of the escarpment adjacent to Red Hill Creek. Leachate collection systems have been installed and the leachate is pumped to the Woodward Avenue STP. An Upper Ottawa Street Landfill Site Study was produced in 1986. Monitoring is performed by the Ministry of Environment and the Region of Hamilton-Wentworth.

The Jersey Road Landfill site in Ancaster was closed in 1980. The 19.8 hectare site has a leachate collection system and the leachate is pumped to the Woodward STP.

The Steetley Industries Landfill site is approximately 16.3 hectares and is located in the Town of Flamborough. The site is limited to non-hazardous solid industrial waste. A leachate system collects leachate for pumping to the Dundas STP. A groundwater monitoring program is performed.

Taro Aggregates Landfill site in Stoney Creek is approximately 24.3 hectares and is also limited to non-hazardous solid industrial waste. A groundwater monitoring program is conducted.

Stelco Inc. Landfill Sites (No. 2 Rod Mill and No. 3 Dock) are approximately 18.5 hectares and 35.4 hectares. They are constructed on landfill in the Harbour and are restricted to non-

putrescible non-hazardous industrial waste. Groundwater monitoring programs are performed by Stelco and annual reports sent to the Ministry of Environment.

IV.1.2.5 Agricultural

The total land area in Hamilton-Wentworth and Halton Regions is 119,949 hectares, of which 96,909 hectares are classed as improved with 81,616 hectares under crops. There are 22,263 hectares of woodland in the two regions. Approximately one half of this acreage is in the Hamilton Harbour watershed. This land is intensively cropped.

The Agricultural Census (1986) reports there are 22,832 hectares of hay, 23,519 hectares of cereal grains, 19,871 hectares of corn, 4,299 hectares of soybeans, 828 hectares of potatoes and 595 hectares of canola grown as the major crops on 2,227 farms.

There are 262 tree fruit farms on 1,454 hectares and 207 farms growing berries and grapes on 945 hectares. 2,879 hectares of vegetables are found on 291 vegetable farms. 11 nursery farms grow 1866 hectares of nursery stock. 12 sod farms grow 652 hectares of sod.

In addition to the crops grown in the two regions, there are livestock produced. There are 2,228,940 hens and chickens, 52246 chicks and pullets less than 20 weeks, 137,373 equal to or greater than 20 weeks, 1,945,364 other chickens and 170,720 turkeys. There are 37,723 total cattle and calves with 8,036 dairy cows. There are 51,042 total pigs and 8,255 sheep.

Farmers apply nitrogen, phosphate and potash fertilizers and lime to field and horticulture crops according to recommendations based on the soil test requirements. The summary of the 1986 Ontario Ministry of Agriculture and Food soil testing information indicates that farmers in the regions of Hamilton-Wentworth and Halton tested 1,487 soil samples. The average soil test values for all crops indicate the soils are neutral in pH with an average phosphorus reading of 32 and an average potassium reading of 124. These average values are slightly higher than the provincial average due to the horticultural crops grown.

At the present time on the average, farmers in the Hamilton Harbour Watershed are not over-fertilizing their soils if they are following the Ontario Soil Testing Recommendations.

The application of high rates of phosphate fertilizer to all crops, including horticultural crops, must be according to soil test recommendations in order to reduce the potential for non-point source loadings of phosphate.

Herbicide and pesticide use in the two regions is summarized in Table 2.

The agricultural use of land in the Hamilton Harbour watershed especially adjacent to watercourses may have some effect on water quality in the rural areas if recommended management techniques are not followed. Where recommended crop and livestock management practices are followed, the impact of agricultural use of land on water quality is expected to be minimal.

Table 2: Herbicide and Pesticide Use in 1983 (kg)
Crop Triazine Phenoxy Other Insect. Fungi.

Hamilton	Field	25350	8070	26460	6670	0
-Wentworth	Fruit	130	10	270	7930	23520
	Veg.	730	310	2420	4850	4980
	Roads		880	110		
Halton	Field	7370	2350	0	0	0
	Fruit	10	0	70	2420	6420
	Veg.	100	10	280	600	760
	Roads		670	20		

IV.1.2.6 Recreational

The Hamilton-Wentworth Conservation Authority has 13 conservation areas in the watershed for a total of approximately 2,000 hectares. Most of these areas support recreational activities such as hiking, bird watching, family picnics, fishing, swimming, canoeing and sailboarding activities. Cootes Paradise is a 835 hectare nature preserve owned and managed by the Royal Botanical Gardens (RBG). Numerous passive recreational activities are supported by Cootes Paradise. Estimates of the public's use of Cootes Paradise and the RBG natural areas for outdoor education and enjoyment is approximately 63,000 user days. The Niagara Escarpment and its associated natural areas and trails is also a major passive recreational resource.

IV.1.2.7 Wildlife Habitat

The Cootes Paradise/Hamilton Harbour area lies within two broad and overlapping life zones: the Great Lakes-St. Lawrence, and the Carolinian (Deciduous Forest Region). The Carolinian life zone is widespread in the eastern United States but only extends into Canada in southwest Ontario between Lakes Huron, Erie and Ontario. Consequently the flora and fauna reflect elements of both of these major biomes. Nationally, provincially, and regionally significant plant and animal species are present. Sixteen rare mammals, 25 rare fish, 53 rare breeding birds, and 22 rare reptiles and amphibians have been identified in the Hamilton-Wentworth Region.

The Niagara Escarpment, Dundas Valley, Red Hill Creek valley and upland areas of Cootes Paradise and Grindstone Creek valley comprise a continuous green belt providing corridors for wildlife utilization within the region.

IV.1.2.8 Environmentally Sensitive Areas

Environmentally sensitive areas (ESAs) are areas with some inherent biological sensitivity, and were identified using the nine criteria described below as areas containing or representing:

- 1) unusual and/or distinctive landforms
- 2) vital ecological functions (water storage, headwaters, habitat)
- 3) unusual/distinctive plant and/or animal communities
- 4) unusual/distinctive habitat
- 5) high diversity of biological communities
- 6) habitat for rare or endangered species
- 7) large and undisturbed area
- 8) other combination of habitat-landforms valuable for research or education
- 9) other combination of habitat/landforms with a high aesthetic value

The Hamilton-Wentworth Region has a total of 44 ESAs of which only 27 are in the Hamilton Harbour watershed (11,400 ha.). The Halton Conservation Authority has a total of 38 ESAs with 5 contained in the watershed (600 ha.). Twenty-five percent of the Hamilton Harbour watershed has been identified as an environmentally sensitive area.

The ESA policy is designed to protect significant natural areas within the limits provided by existing legislation. The intent of the policy is not to unnecessarily restrict development within the ESA, but rather to ensure that such development does not adversely affect the ESA as determined through preparation of environmental impact assessments. In many cases, ESAs may need all or large portions of their area to be protected.

Many of the areas will also be identified by other agencies as special areas (Parkway Belt West Plan, Niagara Escarpment Commission, Class 1 Wetlands, Carolinian Canada, or ANSI (Areas of Natural Scientific Interest)).

IV.1.3 Current Water Uses

IV.1.3.1 Water Supply

The drinking water supply for Hamilton and Burlington residents is Lake Ontario. Water is drawn from intakes 5 kilometers south and north from the Ship Canal. Ultimately, 368,000 m³/day of what originally was Lake Ontario water is processed at the Hamilton and Burlington sewage treatment plants for discharge into Hamilton Harbour.

IV.1.3.2 Navigation

Hamilton Harbour is the second largest Canadian Port on the Great Lakes and ranks sixth for total tonnage in Canada. Imports include general cargo, steel, ingot moulds, machinery and fertilizers. Exports include steel, general cargo, beans, grain, newsprint, rubber, synthetic resin, road graders, ductile iron water pipe and cement. Bulk shipments of coal, iron ore, sand, scrap metal, petroleum products and molasses are handled. In the past ten years, the level of shipping activity in the Harbour has fluctuated. Since 1922, the tonnage handled in the port has steadily increased. Tonnage has levelled off (11 million metric tonnes) and is expected to remain relatively stable with modest yearly increases.

On behalf of the Hamilton Harbour Commission (HHC), Public Works Canada oversees regular maintenance dredging projects which maintain the required navigational depth (approx. 9 m) in the main ship channels and slips. From 1976 to 1984, 350,000 m³ of sediments have been dredged from the Harbour and placed in the confined disposal facility (CDF) managed by the Hamilton Harbour Commission at the east end of the Harbour.

IV.1.3.3 Fish and Wildlife

Hamilton Harbour has six areas within the basin identified as having significant wildlife associations. The areas are: Cootes Paradise, Hendrie Valley/Carrolls Point, the Hamilton Harbour Commission's Confined Disposal Facility, Hydro Islands, Windermere Basin, and Hamilton Harbour proper.

The west end of Lake Ontario, including Hamilton Harbour, is the second most important waterfowl area in Lake Ontario and the fourth most important area in the two lower Great Lakes. The North American Waterfowl Management Plan has specific objectives regarding the acquisition and protection of 27,300 hectares of breeding and migration habitat for Black Ducks and mallards within the Canadian St. Lawrence-Great Lakes Lowlands area.

Cootes Paradise is a Class One Wetland. Given the importance of the area for waterfowl both locally and within the context of the North American Waterfowl Management Plan, Cootes Paradise could achieve regional and national prominence if its waterfowl usage could be improved.

IV.1.3.4 Recreation

The calm waters of the Harbour are enjoyed by many sailing and rowing enthusiasts. Swimming is prohibited by a bylaw of the Hamilton Harbour Commission. Many individuals fish for salmon, trout, bass, pike, and panfish.

At present, 737 boat slips, 250 moorings and 70 dry sail spaces are available in the Harbour. Approximately 70% are occupied by sail boats and 30% by power boats. Four ramps are provided, two in Hamilton and two in Burlington. Seven boat

clubs or marinas are located in the Harbour, with all except one located in the southwest corner of the Harbour. These recreational boating facilities are estimated to provide approximately 78,000 user days per year.

The Ontario Angler Survey and annual creel surveys indicate that fishing activity is predominately in Lake Ontario and oriented toward cold water species. Almost all of the fishing in the Harbour has been observed to be shore fishing. Several warm water and cold water species are caught in the Harbour. The total user days has been estimated to be approximately 4400 per year.

IV.1.3.5 Waste Disposal

The Hamilton and Burlington sewage treatment plants (STPs) discharge into Hamilton Harbour ($391,000 \text{ m}^3/\text{day}$). All industries in Hamilton discharge their wastes to the sewage treatment plant; however, both Stelco and Dofasco discharge a portion of their waste directly to the Harbour after on-site treatment. Combined sewers do overflow during rain events and result in sewage entering the Harbour directly.

IV.1.3.6 Industrial Uses

Both of the iron and steel industries withdraw water for direct contact cooling ($2 \times 10^6 \text{ m}^3/\text{day}$) but virtually all is returned to the Harbour. Discussion concerning effluent discharges (concentrations and loadings) appears in Chapter V "Identification of Pollutant Sources".

IV.1.4 Political Jurisdictions

Hamilton Harbour falls under the purview of a number of jurisdictions, with precedence over the others depending on the Harbour use in question. The main uses and ownership of the Harbour area, therefore, are important considerations in determining the scope of the various jurisdictions and their authority over the Harbour.

Historically, the Constitution Act of 1867 (British North America Act) gave the issue of free navigation primacy over all other uses within public Harbour areas. Public Harbours were the propriety of the federal government. Harbour jurisdiction extended to the bed of the Harbour and to the foreshores of the Harbour where these foreshores were actually used for Harbour purposes. Autonomous Harbour Commissions were created to manage and administer public Harbours on behalf of the federal government.

IV.1.4.1 Hamilton Harbour Commission

In the case of Hamilton Harbour, it was not a public Harbour at the time of Confederation in 1867 and the City of Hamilton, incorporated in 1846, had jurisdiction over the Harbour area. With the Hamilton Harbour Commission Act of 1912, the Hamilton Harbour Commission assumed authority to administer, on behalf of

the City of Hamilton, all waters and inlets of the Bay, and all waterfront properties, water lots, docks, shores, and beaches in and along Hamilton Harbour.

The federal government appoints 2 commissioners to the Hamilton Harbour Commission (HHC). The third commissioner is appointed by the City of Hamilton. The HHC has absolute jurisdiction over lands developed for shipping, navigation, and Harbour purposes. In fact, Section 15(1) of its enabling Act implies that the Commission may regulate and control the use of all Harbour foreshore lands. The HHC passes its own by-laws to control other lands that may interfere with navigation or shipping interests and generally, permits for use must be sought from the Commission.

As indicated in section IV.1.4.5., a court decision in 1978 established some basic principles to guide jurisdiction over Hamilton Harbour land uses. Just as the City can validly regulate land use within the Harbour area, so long as it does not interfere with shipping or navigation uses, the HHC can similarly regulate lands required for its purposes. Where conflicts arise, the paramountly of federal power can be expected to prevail in areas of shipping and navigation. Other land uses along the Harbour foreshore can be accommodated, therefore, but only on the basis of whether or not the land in question is required for shipping or navigation purposes, now or in the future.

IV.1.4.2 Federal

The authorities for federal jurisdiction in Hamilton Harbour derive primarily from the Canada Shipping Act, the Navigable Waters Protection Act, the Public Works Act as it pertains to navigational dredging and the Fishing Act. Although the Hamilton Harbour Commission reports to the Minister of Transport it acts autonomously from the federal government. The federal government owns some water lots adjacent to the Canada Centre for Inland Waters (CCIW).

Apart from the Burlington Ship Canal, which is the responsibility of Transport Canada, the federal government has in the past exerted very little direct jurisdiction over Hamilton Harbour.

Through its treaty power, the federal government can enter into international agreements, such as the Boundary Waters Treaty of 1909 with the United States. This has enabled the Canada-United States Great Lakes Water Quality Agreement and consequently the Canada-Ontario Agreement on Great Lakes Water Quality which impose certain obligations on the various levels of government to reduce pollution inputs into the Great Lakes. Since Hamilton Harbour water discharges into the Great Lakes system, the quality of this water is an important concern.

Federal spending power which allows the government to fund various initiatives can be an important determining factor affecting the direction of development, land/water use, or rehabilitation programs. Federally funded projects are subject to the Environment Assessment and Review Process (EARP). The federal government has also funded the construction and upgrading of municipal sewage treatment plants in the recent past. Other infrastructure works, land use improvement (eg. ARDA) or protection (Southwestern Ontario flood protection), and water basin studies have been funded through general or specific federal/provincial development agreements.

The federal Fisheries Act provides the means to protect fisheries habitat from degradation through pollutant discharge and spills into the aquatic system or direct physical destruction. A Canada - Ontario Fishery Agreement has recently been signed regarding fisheries management in Ontario. Fisheries and Oceans Canada has also recently adopted a policy to improve habitat management and protection. A Canada - Ontario Subsidiary Agreement on the management of fish habitat is currently under discussion.

Under the Canada Water Act, the federal government has authority to enter into agreements with the provinces for the designation of special interest or management watersheds or basins. Such designations allow for joint research and study efforts, or the implementation of various or specific measures to manage the watershed for the enhancement of water quantity or quality. No specific management watershed designation has ever been formally applied in Ontario to date.

IV.1.4.3 Provincial

By virtue of the Constitution Acts of 1867 and 1982, the prime jurisdictional authority over water management is generally held by the provinces. Therefore, the province is the main "water manager" and can determine its apportionment or regulate its quality to meet provincial economic and social objectives. The Constitution Acts give the provinces ownership of public lands, minerals, rivers, and water courses, and jurisdiction over generally all matters of a local/private nature in the province.

In the case of Hamilton Harbour, the Hamilton Harbour Commission in fact regulates activities or works with the Harbour. Through its jurisdiction over pollution control and local works and undertakings, Ontario is the major actor in the regulation of waste disposal into the Harbour. Under the Ontario Water Resources Act (OWRA), the Ministry of Environment is provided with authority to regulate the discharge of sewage and the taking of water by licensing municipal and industrial sewage works, potable water treatment systems and by granting permits to take water. The OWRA also attempts to generally discourage the impairment of any lake, river, or stream through discharges of

polluting substances under recourse of injunction, fine and imprisonment. The Ontario Environmental Protection Act (also administered by MOE) provides for the regulation of the deposit, discharge, or emission of wastes and substances (solid, liquid, gaseous) from industrial processes and the licensing of waste disposal sites and systems. The Ontario Environmental Assessment Act is also applicable to municipal and provincial undertakings, and through regulation could be applied to new undertakings by industry.

There are other provincial legislative instruments which potentially can pertain to the Hamilton Harbour environment. The Public Health Act authorizes the Ministry of Health to advise and set requirements for drainage, water supply, disposal of garbage and sewage. The Ontario Planning and Development Act (Ministry of Housing) allows for the designation of development planning areas, the preparation and approval of development plans, and the requirement for local official plans and zoning by-laws to conform with development plans. The Ontario Municipal Board, created under the Act of the same name, is responsible for approvals under the Planning Act, including zoning by-laws and redevelopment plans, and municipal boundary revisions, amalgamation or annexations under the Municipal Act.

The Ministry of Natural Resources administers the Public Lands Act, the Beds of Navigable Waters Act, the Lakes and Rivers Improvement Act, the Beach Protection Act. These reflect provincial authority on public lands and waters (to dispose by grant, lease, sale; licence water lots); to reserve 25% of shorelands for public use; to enter into beach management agreements with municipalities; to regulate alterations on lakes and rivers and the removal of sand from shorelands (beaches and beds) for commercial purposes.

The Ministry of Agriculture and Foods (OMAF) administers the Ministry of Agriculture and Food Act. This Act provides the Provincial authority to grant assistance to agriculture or any branch of it. Programs such as the Land Stewardship Program and the Ontario Soil Conservation and Environmental Protection Assistance Program are funded to provide grants to farmers for soil conservation projects on agricultural land.

IV.1.4.4 Regional

Each Regional Municipality has its own enabling provincial act. Thus, the Regional Municipality of Hamilton-Wentworth Act and the Regional Municipality of Halton Act generally provide for the development of regional official plans which set out broad land use planning guidelines and the development of zoning by-laws. Also pertinent in this context are the Planning Act and the Municipal Act.

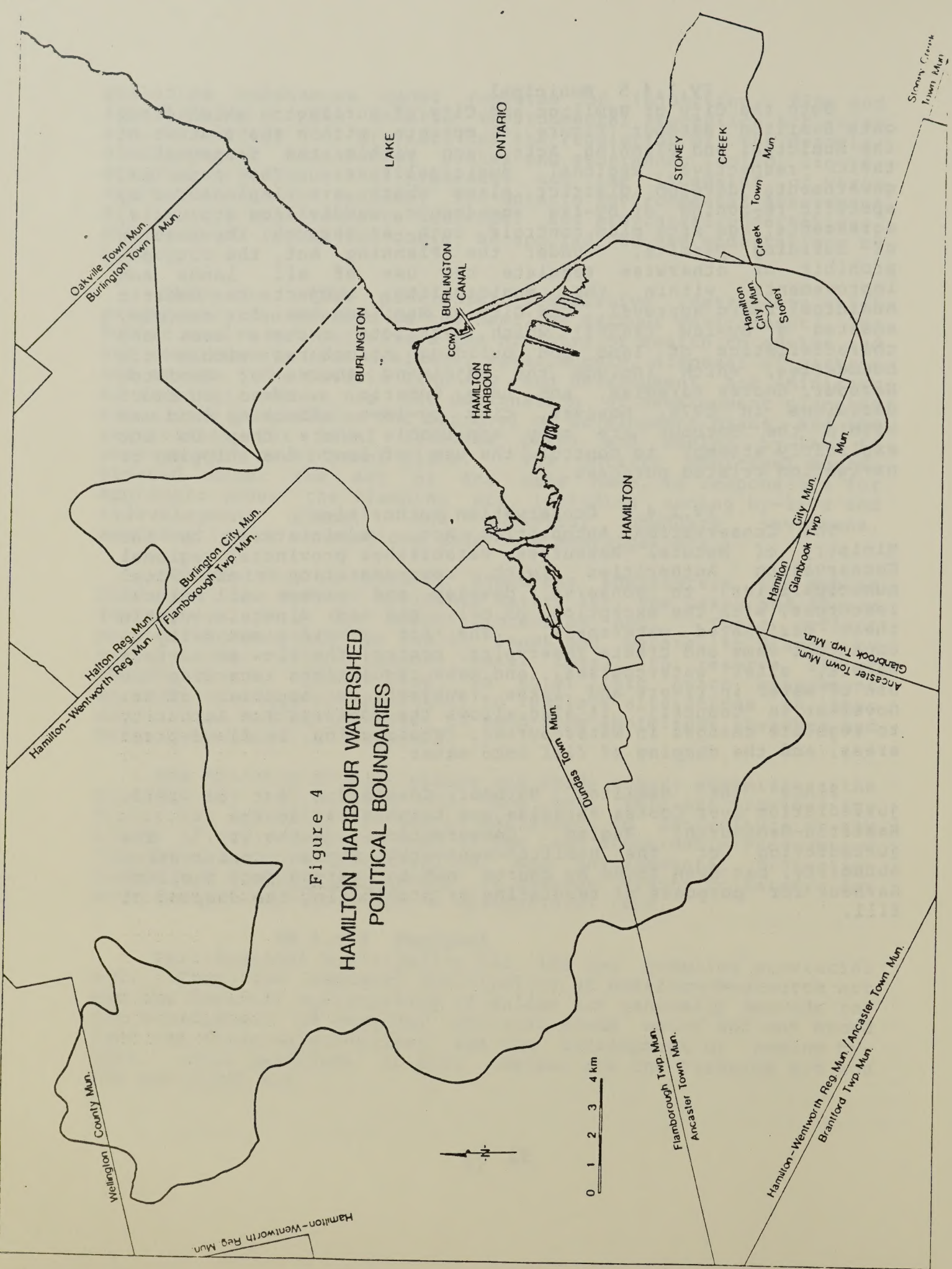
IV.1.4.5 Municipal

Both the City of Hamilton and City of Burlington which front onto Hamilton Harbour (Figure 4) operate within the context of the Municipal and Planning Acts, and within the framework of their respective Regional Municipalities. The municipal governments develop district plans which are implemented by specific re-zoning or by-law amendments, subdivision approvals, agreements, and site plan controls, such as through the issuing of building permits. Under the Planning Act, the City can prohibit or otherwise regulate the use of all lands and improvements within the municipality, subject to Ontario Municipal Board approval. The City of Hamilton has, for example, enacted a by-law (#6593) which restricts certain uses and characteristics of land and building structures within its boundaries, which include the adjoining shores of Hamilton Harbour, Cootes Paradise, and Lake Ontario. Based on court decisions in 1978, however, city by-laws affecting land use within the Harbour are only applicable where they do not explicitly attempt to control the use of land for shipping or navigation related purposes.

IV.1.4.6 Conservation Authorities

The Conservation Authorities Act, administered by the Ministry of Natural Resources, establishes provincial regional Conservation Authorities (with representation of local municipalities) to conserve, develop and manage all natural resources, with the exception of oil, gas and minerals, within their designated watersheds. The Act provides authority to construct dams and create reservoirs, control the flow of surface waters, alter watercourses, and make regulations regarding the use of water in rivers and lakes (subject to approval of Lt. Governor in Council). It also allows the Conservation Authority to regulate changes in watercourses, construction in flood-prone areas, and the dumping of fill into water.

Since the Hamilton Harbour Commission Act of 1912, jurisdiction over Cootes Paradise was transferred to the Hamilton-Wentworth Region Conservation Authority. The jurisdiction of the Hamilton-Wentworth Region Conservation Authority, has been found by courts not to extend into Hamilton Harbour for purposes of regulating or prohibiting the dumping of fill.



IV.1.5 Water, Sediment, and Biota Guidelines and Objectives

IV.1.5.1 Provincial Water Quality Objectives

The Provincial Water Quality Objectives pertinent to the present and future uses of Hamilton Harbour are a set of narrative and numerical criteria designed for the protection of aquatic life and recreation in and on the water. They represent a desirable level of water quality that the Ministry strives to maintain in surface waters of the Province. The Objectives for raw water supplies for drinking water are generally not as restrictive as the Objectives for the protection of aquatic life.

The Objectives for recreational water uses are based on public health and aesthetic considerations. The Objectives for aquatic life are set at such values as to protect all forms of aquatic life and all aspects of the aquatic life cycles. The clear intention is to protect all life stages during indefinite exposure to the water. When insufficient information exists to develop an Objective, a Guideline is provided with the understanding that site-specific information would be necessary to manage the water body with respect to the chemical in question. Phosphorus is an example where the Province has supplied only a Guideline.

Table 3 illustrates the Provincial Water Quality Objectives for those chemicals which have previously violated the Objectives in Hamilton Harbour. If a chemical is not listed in the table, then the chemical has routinely met the Objective in the Harbour.

IV.1.5.2 Canadian Water Quality Guidelines

Recently, the Task Force of Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers published Canadian Water Quality Guidelines (CCREM, 1987). The federal Guidelines have specific Guidelines for recreational water quality and for the protection of freshwater aquatic life. Guidelines for some of the chemicals vary with water hardness, temperature or pH. The values reported in Table 3 are adjusted for the hardness and pH conditions within Hamilton Harbour.

IV.1.5.3 IJC Water Quality Objectives

The International Joint Commission also has water quality Objectives. The IJC Objectives are also included in Table 3. The Objective for phosphorus is to minimize eutrophication problems and to prevent degradation with regard to phosphorus in the boundary waters of the Great Lakes System. The goals of phosphorus control are specified in Annex 3 of the Great Lakes Water Quality Agreement of 1978. The goal most appropriate to Hamilton Harbour is the elimination of algal nuisance in bays and in other areas wherever they occur.

Table 3: Water Quality Objectives
(All units in $\mu\text{g/l}$ unless specified)

Parameter	Provincial	Objective Federal	IJC
Arsenic	100	50	50
Cadmium	0.2	1.3	0.2
Copper	5	3	5
Cyanide	5	5	5
Diss. Oxygen	4-5 mg/l	5-6 mg/l	6 mg/l
Iron	300	300	300
Lead	25	4	5
Mercury	0.2	0.1	0.2
Nickel	25	110	25
Nitrogen (ammonia)	20 $\mu\text{g/l}$ un-ion.	.4-2 mg/l tot.	20 $\mu\text{g/l}$ un
Phosphorus	Site specific-	guideline of 20 $\mu\text{g/l}$	
Zinc	30	30	30
Phenol	1	1	1
DDT	3 ng/l	1 ng/l	3 ng/l
PCBs	1 ng/l	1 ng/l	0.1 $\mu\text{g/g}$ fish
Mirex			5 ng/l
γ -BHC	10 ng/l		
Total Diss. Solids		500 mg/l*	200 mg/l
Turbidity	10% Secchi increase	10 mg/l susp. solids increase	10% Secchi
Clarity	1.2 m Secchi	1.2 m Secchi	
Fecal Coliforms	100 /100 ml	200/100ml	
Total Coliforms	1000/100 ml		

* Drinking Water Objective

IV.1.5.4 Water Quality, Habitat and Use Objectives for Cootes Paradise

In response to requests from the Ontario Ministry of Environment, the Royal Botanical Gardens established water quality (Table 4), habitat and use objectives for Cootes Paradise in 1975. The intent of the objectives was to ensure that plant and animal life were not depressed or killed by chemical substances or suspended solids from upstream areas. The objectives were intended to be realistic levels of chemical concentration that will ensure the survival of fish, bottom fauna, insects and plant life in all parts of Cootes Paradise.

Table 4: Water Quality Objectives for Cootes Paradise

Chlorophyll (May-October)	Maximum	50 $\mu\text{g/l}$
Ammonia (un-ionized)		20 $\mu\text{g/l}$
Turbidity (Jackson Units)		25 JU
BOD (effluent quality)		< 5 mg/l
Dissolved Oxygen		> 4 mg/l
Chlorine		< 0.11 mg/l

Habitat Goals

The open water area of Cootes Paradise is currently 375 hectares (1975). It is anticipated that approximately 50% or 190 hectares will be suitable for macrophyte restoration and manipulation with the goal of producing a high quality habitat complex for waterfowl and other marsh-dependent wildlife.

Objectives

1. First and foremost, to maintain this water and marsh habitat with contiguous lands as a wildlife sanctuary by protecting the integrity of habitats for a rich variety of flora and fauna through a firm stand on all activities which interfere with diverse ecological interactions and militate against such a preservation policy.

2. Secondly, to provide limited public access and interpretative facilities for public education and quiet appreciation only to an extent consistent with above.

3. Thirdly, to continue to provide reasonably natural aquatic and terrestrial habitats for studies in environmental science by students at all levels.

Use Goals

The objective is to ensure that Cootes Paradise becomes a suitable aquatic habitat for the following natural biological components, for aquatic biological studies and for specific limited aspects of public recreation.

For Resident Organisms

The aquatic habitat of Cootes Paradise must be made suitable for the needs of a full range of resident organisms common to similar habitats in southern Ontario. These include birds, animals, amphibians, invertebrates and plants. Advanced pollution reduces diversity: the goal here is to achieve diversity in these components through water quality improvement.

For Migratory Birds and Spawning Fish

Cootes Paradise, with other major natural aquatic areas, plays an important role in successful bird migration, (particularly waterfowl) in both spring and autumn. Water quality influences the production of food and cover for migrating waterfowl.

Both native and introduced lake fish enter Cootes Paradise and its tributaries to spawn. Water quality must be conducive to their survival and for the survival of fry which hatch and journey back to Lake Ontario. Water quality must be such that Cootes Paradise can play its part in regeneration of fish to serve the resurgence of fishing in Lake Ontario.

For Aquatic Studies

Present high coliform counts in the inflows of Chedoke Creek and upper Desjardin Canal prevent any use of these areas for aquatic studies beyond those of researchers trained to work in polluted waters. Water quality must be such that school classes and the public on interpretive excursions will not contract skin diseases or infections in handling specimens or by dipping into the water. Many unique research opportunities exist with McMaster University which is within walking distance of Cootes Paradise.

For Recreation

While it is not suggested that the waters of Cootes Paradise meet the standards of total immersion sports, coliform counts must be drastically lowered for quiet boating to be encouraged without health hazard.

IV.1.5.5 Provincial Dredging Guidelines

The Ministry of Environment has Guidelines for the open-water disposal of dredged sediment (Table 5). If the sediments exceed the Guidelines then the sediment must be contained in a confined disposal facility. The Hamilton Harbour Commission manages such a facility on the east shore of the Harbour, south of the shipping canal. The Ministry of Environment is in the process of drafting new sediment guidelines for the dredging of sediments. The guidelines have been expanded to include a higher set of contaminant concentrations for dredging and confinement in a restricted disposal facility. A restricted CDF would differ from an unrestricted CDF in that, leachate tests would be required on the dredgate and the area must be capped with clean material after completion. These guidelines for restricted CDFs are not official as yet but are being used by the regional staff when necessary. The United States Environmental Protection Agency also has guidelines for the classification of contaminated sediments. The EPA heavily polluted criteria are included in Table 5 for comparison.

Table 5: MOE Guidelines of disposal of dredged sediment
(All units in $\mu\text{g/g}$ unless otherwise specified)

	Unrestricted CDF	Restricted CDF	EPA Heavily Polluted
Organic Content	6%		>8%
Sediment Oxygen Demand	50 mg/g		>80
Ammonia (NH_3)	100		>200
Total Kjeldahl Nitrogen	2 mg/g		>2
Total Phosphorus	1 mg/g		>0.65
Iron (Fe)	10 mg/g	35	>25
Copper (Cu)	25 $\mu\text{g/g}$	100	>50
Chromium (Cr)	25	120	>75
Nickel (Ni)	25	60	>50
Zinc (Zn)	100	500	>200
Lead	50	500	>60
Cadmium	1	4	>6
Mercury	0.3	0.5	>1
Cobalt	50		
Arsenic	8	20	>8
Ether Ext.	1.5 mg/g		>2
PCBs	0.05	2	>10

IV.1.5.6 Fish Consumption Guidelines

The Ontario Ministry of Environment, Ministry of Natural Resources and the Ministry of Labour cooperate in a monitoring program called the Sport Fish Testing Program. Annually the "Guide to eating Ontario Sport Fish" is published providing advice on recommended levels of consumption of game or sport fish from over 1400 of Ontario's lakes, rivers and locations on the Great Lakes. The substances included in the monitoring program are: mercury, copper, nickel, zinc, cadmium, manganese, chromium, arsenic, selenium, lead, PCBs, DDT, Mirex, Dioxin, HCB (hexachlorobenzene), Lindane, Heptachlor, Aldrin, Chlordane, and Toxaphene.

The consumption guidelines are based on the Canadian government health protection guidelines. The guidelines reflect the maximum recommended consumption of fish according to the contaminant content and the duration of the consumption (one, two, three weeks and long-term).

IV.2 DESCRIPTION OF ENVIRONMENTAL CONDITIONS

IV.2.1 Water Quality

IV.2.1.1 Eutrophication

Ammonia and nitrate are present in the Harbour in excessive concentrations relative to the requirements for the growth of algae. Ammonia concentrations are a function of loadings versus biological processes and flushing losses to Lake Ontario. The important biological processes are algal uptake and bacterial nitrification (the conversion of ammonia to nitrate) which are

dependant on temperature. Therefore, ammonia concentrations are high in the spring due to accumulated loadings during the winter and the lack of nitrification and algal uptake. In the spring of 1985, ammonia concentrations in the centre of the Harbour were approximately 2000 $\mu\text{g/l}$ $\text{NH}_3\text{-N}$. The concentration decreased with the onset of warmer temperatures to average values of 300-400 $\mu\text{g/l}$ during summer. Average nitrate concentrations during the early 1980s were 1.7 mg/l . Nitrate concentrations begin the season at the average concentration and then increase through spring and early summer due to the nitrification of ammonia to nitrate. The concentration then decreases through the summer and fall, presumably due to algal uptake and reduced nitrification rates.

Total phosphorus concentrations in 1985 declined from a May high of 87 $\mu\text{g/l}$ to an October low of 37 $\mu\text{g/l}$. The seasonal average concentration was 64 $\mu\text{g/l}$. Filtered reactive phosphorus, which is generally believed to represent a readily available form of phosphorus to algae, had a seasonal average concentration of 24 $\mu\text{g/l}$. A summer decline of the reactive phosphorus was apparent during 1986 and 1987.

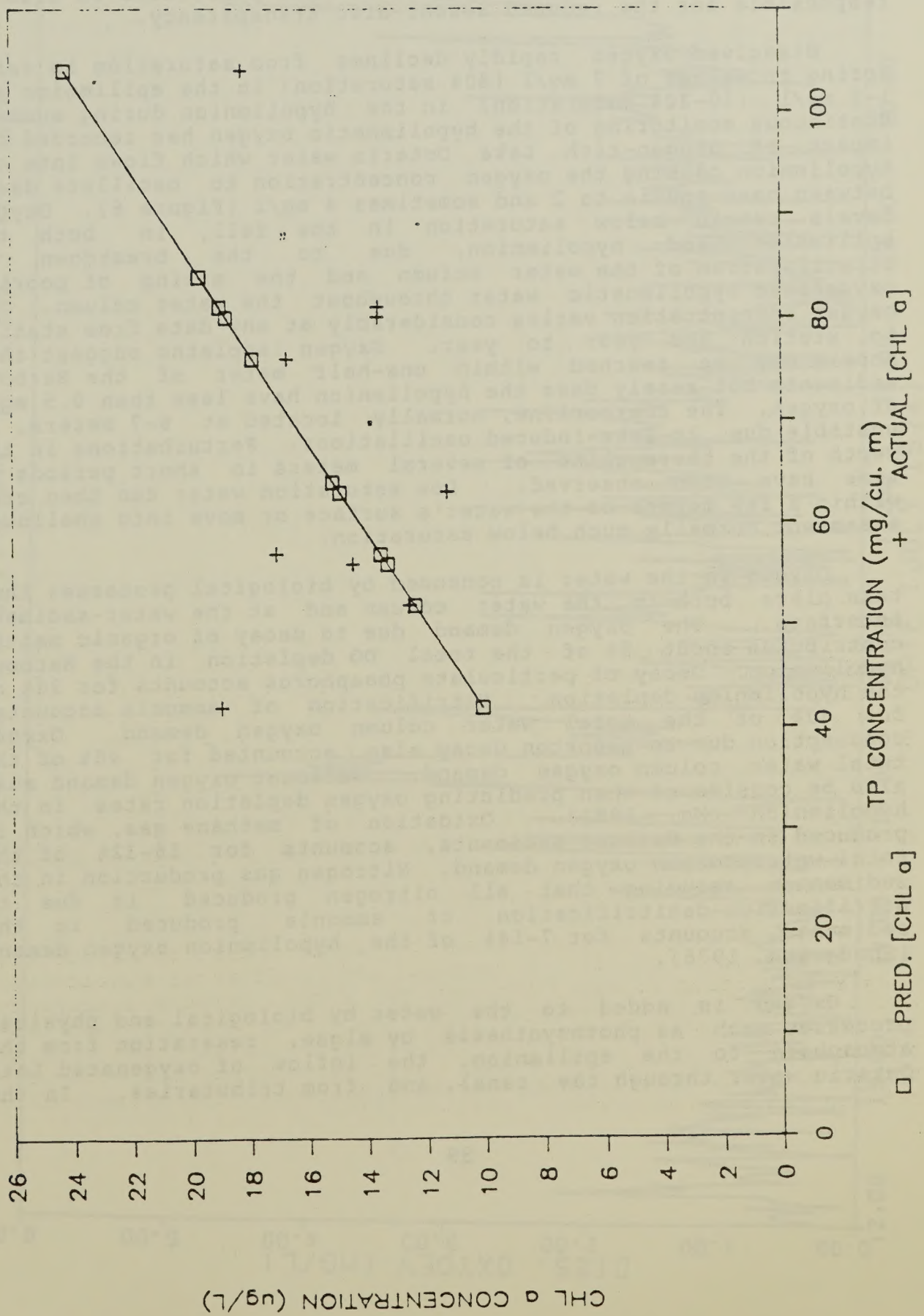
The summer chlorophyll a concentration (a measure of algal abundance) in the surface waters of the Harbour was 27 $\mu\text{g/l}$ in 1985. The seasonal average for all stations at all depths was 13.5 $\mu\text{g/l}$. The Janus-Vollenweider empirical model relating phosphorus loading and basin retention times to the annual average chlorophyll concentration suggests that the chlorophyll concentration in the Harbour is similar to other lakes around the world, provided the total phosphorus concentration remains below 70 $\mu\text{g/l}$. During the past decade, the response of seasonal average chlorophyll (all stations/all depths) to the seasonal average phosphorus concentration has probably not been statistically significant. Chlorophyll concentrations have averaged between 13-18 $\mu\text{g/l}$ while total phosphorus concentrations have averaged between 40-100 $\mu\text{g/l}$ during the past decade (Figure 5). The soluble reactive phosphorus half-saturation constant for modelling algal growth in Hamilton Harbour is 10 $\mu\text{g/l}$ (Ng, 1981). From 1984 to 1986, soluble reactive phosphorus (SRP) averaged 13 $\mu\text{g/l}$ but during 1987, SRP averaged only 2.5 $\mu\text{g/l}$ in the surface waters at the centre of the Harbour. According to the model, the recent phosphorus concentrations would be one of the factors limiting algal growth.

Water clarity, as determined by Secchi disc transparency, had an average of 1.4 meters in 1986. If water clarity was solely a function of algal biomass, the Secchi disc transparency would be predicted by the OECD empirical model to be between 1.5-2.5 meters. Carlson (1977), however, would predict a Secchi disc transparency of only 0.8 - 1.3 m with the current chlorophyll a concentrations. Harris and coworkers examined the relationship between chlorophyll and water clarity as determined by light

Figure 5

HAMILTON HARBOUR

TP CONC. VS. CHL α CONC.



extinction through the water column and observed a relationship in 4 out of 5 years. However, chlorophyll explained only 11-30% of the variability in light extinction (Harris et al., 1979; Sephton and Harris, 1984). Other factors such as suspended silt and dissolved substances causing colour are postulated to also be responsible for the reduced Secchi disc transparency.

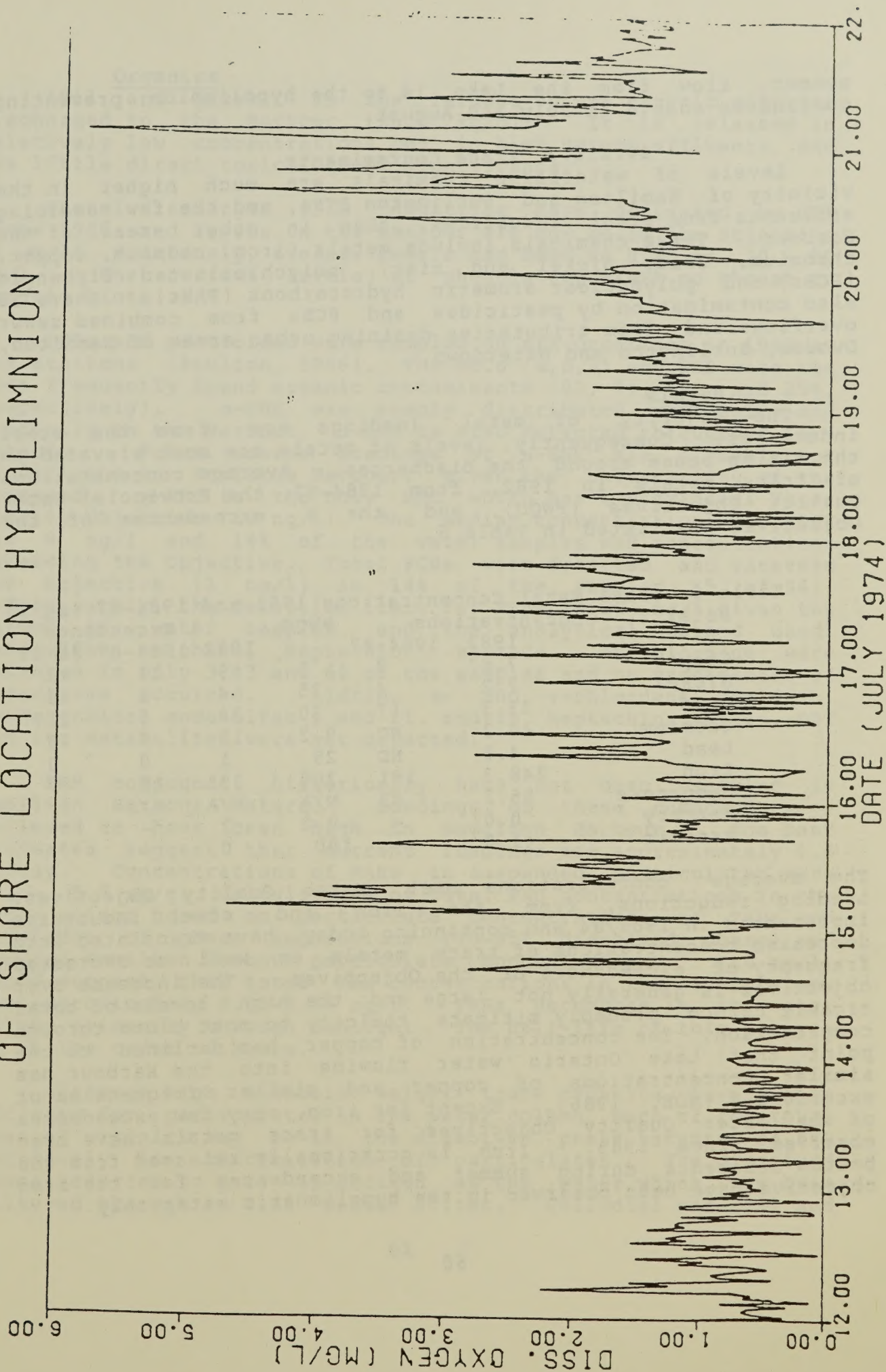
Dissolved oxygen rapidly declines from saturation in early spring to values of 7 mg/l (80% saturation) in the epilimnion and 1-2 mg/l (10-20% saturation) in the hypolimnion during summer. Continuous monitoring of the hypolimnetic oxygen has recorded the impact of oxygen-rich Lake Ontario water which flows into the hypolimnion causing the oxygen concentration to oscillate daily between near anoxia to 2 and sometimes 4 mg/l (Figure 6). Oxygen levels remain below saturation in the fall, in both the epilimnion and hypolimnion, due to the breakdown of stratification of the water column and the mixing of poorly-oxygenated hypolimnetic water throughout the water column. The oxygen concentration varies considerably at any date from station to station and year to year. Oxygen isopleths suggest that anoxia may be reached within one-half meter of the Harbour sediments but rarely does the hypolimnion have less than 0.5 mg/l of oxygen. The thermocline, normally located at 6-7 meters, is unstable due to Lake-induced oscillations. Perturbations in the depth of the thermocline of several meters in short periods of time have been observed. Low saturation water can then come within a few meters of the water's surface or move into shallower areas not normally much below saturation.

Oxygen in the water is consumed by biological processes that take place both in the water column and at the water-sediment interface. The oxygen demand due to decay of organic matter contributes about 5% of the total DO depletion in the Harbour hypolimnion. Decay of particulate phosphorus accounts for 20% of the hypolimnion depletion. Nitrification of ammonia accounted for 40% of the total water column oxygen demand. Oxygen consumption due to plankton decay also accounted for 40% of the total water column oxygen demand. Sediment oxygen demand must also be considered when predicting oxygen depletion rates in the hypolimnion (Ng, 1981). Oxidation of methane gas, which is produced in the Harbour sediments, accounts for 16-32% of the total water column oxygen demand. Nitrogen gas production in the sediments, assuming that all nitrogen produced is due to nitrification-denitrification of ammonia produced in the sediments, accounts for 7-14% of the hypolimnion oxygen demand (Snodgrass, 1976).

Oxygen is added to the water by biological and physical processes such as photosynthesis by algae, reaeration from the atmosphere to the epilimnion, the inflow of oxygenated Lake Ontario water through the canal, and from tributaries. In the

Figure 6

DISSOLVED OXYGEN RESULTS OFFSHORE LOCATION HYPOLIMNION



summer, flow from the Lake is to the hypolimnion, preventing continuous anoxia in July and August.

IV.2.1.2 Trace Contaminants

Levels of waterborne chemicals are much higher in the vicinity of Hamilton and Burlington STPs, and the few remaining effluents from steel industries, than in other areas of the Harbour. These chemicals include metals (iron, cadmium, copper, chromium, lead, nickel and zinc), polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs). There is also contamination by pesticides and PCBs from combined sewer overflows and from tributaries draining urban areas of Hamilton, Dundas, Burlington and Waterdown.

Metals

The majority of metal loadings are from the steel industries. Consequently, levels of metals are most elevated in the mixing zones around the discharges. Average concentrations of trace metals in 1982, from 1984-87, the Provincial Water Quality Objectives (PWQO), and the % exceedences of the Objectives are listed in Table 6.

Table 6: Trace Metal Concentrations 1982 and 1984-87 ($\mu\text{g/l}$)

Metal	Concentrations		PWQO	% Exceedence		
	1982	1984-87		1982	1984-87	86-87
Copper	7.6	3	5	69	11	<1
Nickel	7.2	4	25	4	1	<1
Zinc	23.3	17	30	30	6	2.7
Cadmium	<0.2	ND	0.2	19	9	0
Lead	4.8	ND	25	1	0	0
Iron	248.3	191	300	33	15	9
Manganese	56.2	82	N/A	N/A	N/A	
Mercury	0.07	-	0.2	2	-	
Arsenic	<1.0	-	100	0	-	

The average concentrations meet Water Quality Objectives. Loading reductions, from the iron and steel industries implemented in 1983/84 and continuing today, have translated into decreased concentrations of trace metals as well as decreased frequency of exceedences of the Objectives. The increase over objectives is generally not large and the high levels of total organic carbon probably mitigate toxicity to most biota through complexation. The concentration of copper has declined to the point that Lake Ontario water flowing into the Harbour has similar concentrations of copper and similar frequencies of exceedences (MOE, 1986). Except for iron, very few exceedences of the Water Quality Objectives for trace metals have been observed since 1985. Iron is occasionally released from the bottom sediments during summer and exceedences for the iron objective have been observed in the hypolimnetic water only.

Organics

'Oil and grease' is the largest volume organic material discharged to the Harbour (2600 kg/d). It is released in relatively low concentrations but in high volume effluents, and has little direct toxicological significance.

Phenol discharges from industries have decreased by 96% since 1965 and levels in the Harbour are now below the objective (1 $\mu\text{g/l}$). Previously, average levels had been as high as 10 - 50 $\mu\text{g/l}$. The current levels of phenols represent no threat to aquatic biota.

PCBs and pesticides were sampled on six occasions in 1982 at six stations (Poulton, 1986). The BHCs (α, β, γ) and HCB were the most frequently found organic contaminants (92, 14, 69, and 25%, respectively). α -BHC was evenly distributed seasonally and spatially in the Harbour. α -BHC is also detected throughout Lake Ontario. Point source loadings of α -BHC are probably not significant in Hamilton Harbour, given the universality of the compound. γ -BHC is the only BHC which has a Provincial Water Quality Objective (10 ng/l). The median concentration of γ -BHC was 8 ng/l and 14% of the water samples had concentrations exceeding the Objective. Total PCBs were detected and exceeded the Objective (1 ng/l) in 14% of the samples (5 of 36). Unfortunately, the detection limit for PCBs is 20 ng/l given the volume of water sampled and the analytical method used. Endosulfan sulphate, Heptachlor epoxide, oxychlordane were detected in only 3, 3 and 6% of the samples and no exceedences of Objectives occurred. Aldrin, α - and γ -chlordane, dieldrin, methoxychlor, endosulfan I and II, endrin, heptachlor, mirex, DDT and its metabolites were not detected.

PAH compounds, historically have not been sampled in Hamilton Harbour waters. Loadings of these compounds were believed to have been high in Hamilton Harbour. The best estimates suggest that current loadings are approximately 1.8 kg/day. Concentrations of PAHs in suspended particulates were 3.3 - 5.5 $\mu\text{g/g}$. Calculations of total PAH concentrations in the water column based on particulate concentrations of PAHs and knowledge of phase separations (70-95% dissolved phase) and typical Hamilton Harbour particulate concentrations (10 mg/l) would suggest that total PAH concentrations in the water column are approximately 0.15-0.88 $\mu\text{g/l}$. PAHs decompose in the water column primarily through sunlight. The half-life of this process is in the order of hours.

Although high molecular weight trace organics have a high affinity for particulates in the water column, much of the total mass of organics may be in the dissolved phase because of the relatively low concentration of particulates. The dissolved phase referred to here is defined as the water which has been filtered through a 0.45 micron filter. Colloidal material and

macromolecules will pass through a 0.45 micron filter. Trace organics are hydrophobic and will become adsorbed to particulates such as soil particles and colloidal particles. Due to the low concentration of large particles in the water column, the majority of hydrophobic organic compounds will remain in the dissolved phase or become attached to colloidal material. Since colloidal material will not settle out of the water column due to their small size, for all practical purposes, colloidal material and any associated organic contaminants are considered to be in the dissolved phase.

IV.2.1.3 Harbour Circulation

The Harbour is very dynamic, and a strong, permanent thermocline does not develop in the Harbour during the summer. The large Lake-Harbour exchange flowing through the Burlington Canal, combined with wind-induced motion, produces large changes in the vertical thermal structure and a very high degree of small scale variability or patchiness in the thermal, chemical and biological properties of the Harbour.

The exchange through the Burlington Ship Canal comprises the largest component in the water balance of the Harbour and has a major effect on water quality in the Harbour. The flow through the canal is driven by differences in water levels between Lake and Harbour, and by differences in density (due to temperature differences) between Lake and Harbour. Wind-driven surface drift currents may also be important at times. All of these forcing mechanisms exhibit fluctuations on a wide range of time scales, from minutes to weeks or longer. As a result, the flow in the canal is itself highly unsteady with frequent flow reversals. As well as being unsteady, the velocity profiles within the channel exhibit complexity with depth, particularly under conditions of thermal stratification during summer. The temporal and vertical spatial variability make accurate gauging of discharge in the canal difficult. As a result, uncertainty surrounds the basic water budget for the Harbour.

Kholi (1984) has presented monthly estimates for all major inflows and outflows, including Lake-Harbour exchange, for the period May 1979-April 1980. His figures are based on a method for analyzing current meter records in terms of the excursion length of water particles between flow reversals (Kholi, 1979). Kholi's results indicate an average annual inflow to the Harbour for all land-based sources of $6.46 \times 10^5 \text{ m}^3/\text{day}$, or a replacement of 0.23% of the total Harbour volume of $2.8 \times 10^8 \text{ m}^3$ every day, on average. The corresponding average retention time or flushing time (Harbour volume divided by flow rate) is 430 days. However, the total annual flow out of the Harbour (which includes land-based plus Lake sources) is estimated by Kholi as $3.32 \times 10^6 \text{ m}^3/\text{day}$; the corresponding daily replacement is 1.2% and the retention time is reduced to 84 days. Kholi's results show

higher flows from the Lake to the Harbour in winter (November-January) with lower flows in summer. Kholi's (1984) report also summarizes water budget estimates calculated by Snodgrass (1981).

Klapwijk and Snodgrass (1985) discussed the difficulties inherent in measuring long term Lake-Harbour exchanges directly with current meters and suggested that flushing rates could be estimated using a mass balance for conservative dissolved substances, as measured by conductivity. The conductivity (and hence the concentration of dissolved substances) of the Harbour waters depends on the discharge and concentration of dissolved solids in the inputs to the Harbour from runoff, industry, and sewage treatment plants, and on the amount of flushing of the Harbour by Lake Ontario. Lake Ontario has a markedly lower dissolved substance content than the Harbour inflows. Hence it is possible, in principle, to solve a mass balance for the Lake-Harbour exchange, given all other inputs. However, as they point out, not all inputs are known with certainty, and they discuss the assumptions necessary to arrive at a mass balance. Klapwijk and Snodgrass (1985) estimate a mean annual flow from all land based sources of $9.5 \times 10^5 \text{ m}^3/\text{day}$ for June 1977 to May 1978 corresponding to a replacement rate of 0.34% of the Harbour volume per day or a retention time of 295 days. The total annual average flow out of the Harbour is estimated as $3.8 \times 10^6 \text{ m}^3/\text{day}$ corresponding to a replacement rate of 1.4% of the Harbour volume per day or a retention time of 74 days. Hence both Klapwijk and Snodgrass (1985) and Kholi (1984) give estimates for the annual average total discharge out of the Harbour which are of the same order of magnitude, and both indicate that Harbour-Lake exchange is responsible for significantly reducing the flushing time of the Harbour to 20-25% of its value in the absence of such an exchange. However, the monthly pattern of flows given by Klapwijk and Snodgrass have a distinct peak in the late summer and autumn months (July- October) in contrast to the pattern of flows given by Kholi.

The rate at which the Harbour is flushed by cleaner Lake Ontario water provides the simplest index for water quality considerations. However, the calculation of a flushing time or retention time is meaningful only if a water body mixes completely with the flows used in the flushing time calculation. If the flows are short-circuited from their point of inflow to the Harbour outlet without completely mixing with the main body of the Harbour, the flows will have less impact on concentrations within the Harbour. Short-circuiting can occur in two ways. Barica et al. (1987) have pointed out that under some circumstances flow from the Hamilton and Burlington STPs could follow a path along the eastern shoreline directly to the Harbour outlet without first extensively mixing with the main body of the Harbour. Obviously, this would be beneficial for the Harbour, but would result in higher concentrations in the outflow plume from the Harbour to Lake Ontario. The second short-circuiting

mechanism involves the oscillation of the Lake-Harbour exchange, as exhibited by the frequent flow reversals in the Burlington Ship Canal. The measurement and explanation of the periodicities associated with these oscillations has been a subject of great interest and study (MOE 1974, 1977 Freeman et al., 1974 Palmer and Poulton 1976). If the reversals occur more rapidly than mixing and circulation in the Harbour or in the coastal region of Lake Ontario, then a water mass would retain its identity as it oscillated from Lake to Harbour and back again. Lake water may thus be short-circuited out of the Harbour before effective exchange with Harbour water can take place. However, it is possible that lake water entering the Harbour is retained within the Harbour because of density effects. This may occur if the lake water is colder, and hence heavier, than Harbour water in the upper 10 m (the canal depth) of the water column. The importance of relative density effects for Harbour flushing will be considered briefly later.

Mixing of Lake water within the Harbour could occur by large scale Harbour circulation advecting Lake water away from the canal or less efficiently by smaller-scale turbulent diffusive processes in the vicinity of the Canal entrance. Under conditions of thermal stratification, a further mechanism arises from the spreading of denser Lake water along lines of constant density within the Harbour. These intrusive motions are driven by pressure gradients set up by horizontal density differences between Lake water and Harbour water. Evidence for the presence of intrusions of oxygen rich lenses of water between the Harbour entrance and the middle of the Harbour has been noted by several investigators (Harris et al., 1980 MOE 1975, 1977, 1985).

Part of the discrepancy between the water balances derived from current meter measurements and the dissolved solids balance may be due to short circuiting by the oscillatory nature of the Lake-Harbour flows. Kholi's (1979, 1984) calculations do exclude water motions with very short excursions, up to one half the length of the Canal. Water at the MOE current meter station undergoing such short excursions would remain within the confines of the Canal. It may be that excursions up to twice this distance or longer could represent water movements for which minimal mixing or exchange occurs, but nevertheless should, strictly speaking, be included in a water balance. The mass balance technique, on the other hand, is by its nature a better indicator of the actual net effect of mixing between Lake and Harbour waters, although subject to large uncertainties in the measurement of the balance's many required inputs.

From the above discussion it is clear that two separate questions must be answered to understand the role of Lake-Harbour exchange in flushing the Harbour. The first question concerns how to quantify the flows into and out of the Harbour through the canal itself. As noted above, agreement still does not exist on

this very basic issue, even on a monthly time scale. The second question involves the fate of Lake water once it enters the Harbour: under what conditions is Lake water retained within the Harbour for a time long enough to have a beneficial effect on water quality? The answers to this second question depend on mixing and circulation in the Harbour rather than on the hydraulics of flow in the canal.

Mixing of Lake water within the Harbour could occur by large scale Harbour circulation advecting Lake water away from the canal or less efficiently by smaller-scale turbulent diffusive processes in the vicinity of the canal entrance. If Lake and Harbour waters are at different temperatures, density effects may determine the fate of incoming Lake water (Fischer et al. 1979 pp 209-212). It is often the case that Lake water temperatures are colder than Harbour water temperatures. If colder Lake water flows into the Harbour (whether or not the flow in the canal itself is temperature stratified) then the colder Lake water will plunge below the Harbour water and form an underflow along the Harbour bottom, following the steepest path down the bathymetric contours. Such an underflow will continue along the bottom until it reaches a depth at which there is water of the same density. The Lake water will then flow as an intrusion along a surface of constant density within the Harbour. Evidence for the presence of such intrusions, such as oxygen rich lenses of water between the Harbour entrance and the middle of the Harbour has been noted by several investigators (Harris et al. 1980; MOE 1975, 1977, 1985).

It is important to realize that once the flow reaches a depth below that of the bottom of the canal (approximately 10 m), the water in that underflow below that depth is trapped within the Harbour. It cannot flow back uphill and out through the canal. The water will remain within the Harbour until it is displaced upward by still colder inflows, or mixed vertically within the water column by atmospherically driven processes such as wind stirring or surface cooling.

The frequency with which Lake water forms an underflow in the Harbour is obviously a statistic of considerable importance for Harbour water quality. No concurrent study of water temperature profiles at either end of the canal has been made, but a glance at data from MOE (1985) for temperatures in the Harbour and from Dobson (1984; Figs. 35, 38) for Lake Ontario, indicates that underflow may be frequent and may occur at any time of year. The dominant pattern of Lake-Harbour exchange may thus be one in which water from Lake Ontario enters the hypolimnion of the Harbour, displacing Harbour water upward, with water from the epilimnion of the Harbour comprising the outflow from the Harbour. Klapwijk and Snodgrass (1985) have included this pathway as one possible circulation in their model, although their model predicts a higher frequency of Lake inflow to the

epilimnion of the Harbour. However, their model does not include any consideration of the dynamics of density stratified flow and is based only on approximate heat and salt balances.

The pattern of Lake-Harbour exchange is also relevant to impacts on Harbour water quality of landfilling around the perimeter of the Harbour. The results of Freeman et al. (1974) and Dick and Marsalek (1973) have shown that the duration and magnitude of flows from Lake Ontario to the Harbour depend on the surface area of the Harbour. Decreasing Harbour surface area decreases the total annual volume of inflow from the Lake. This is essentially because decreasing the surface area decreases the volume inflow required to overcome a given water level deficit between the Harbour and the Lake. (Naturally there will be less total outflow from the Harbour to the Lake as well). For detailed derivation of this result the reader is referred to the original papers. Dick and Marsalek state that landfilling from 1926 to 1972 resulted in a decrease in Harbour surface area of approximately 25%, from $2.8 \times 10^7 \text{ m}^2$ to $2.1 \times 10^7 \text{ m}^2$. They estimate that the total volume of the Lake water entering the Harbour annually decreased by approximately $3.2 \times 10^8 \text{ m}^3$ over that period as a result. Their calculations included the effects of surface area changes on water levels as well as flows. Moreover, their results indicated that percentage decreases in surface area and annual inflows were roughly equal and therefore, the 25% decrease in surface area given above resulted in an estimated 24% decrease in inflow volume from $1.35 \times 10^9 \text{ m}^3/\text{year}$ to $1.03 \times 10^9 \text{ m}^3/\text{year}$. (This latter figure is roughly equal to the $1.04 \times 10^9 \text{ m}^3/\text{year}$ for Lake inflow deduced from Klapwijk and Snodgrass's figures cited earlier). Dick and Marsalek concluded that further percentage decreases in Harbour surface area would result in roughly equal percentage decreases in Lake inflows.

The question arises, then, as to the effect of decreasing Lake inflow on Harbour water quality. Intuitively one would expect that a decrease of Lake water inflow of 24% could not fail to have a deleterious effect on Harbour water quality. While the impact of Lake inflows on Harbour water quality is beyond the scope of this chapter, it may be worthwhile to briefly examine the relationships between Harbour volume, inflow rate, and residence or flushing time. In general, residence time T for any volume of water can be defined as the volume V divided by the throughflow Q (assumed equal to the inflow and to the outflow):

$$T = V/Q. \quad (1)$$

One can use Eq. 1 to derive an estimate for the change in residence time dT due to changes in volume dV and flow dQ as (to first order):

$$dT/T = dV/V - dQ/Q, \quad (2)$$

i.e. the relative change in T is equal to the relative change in V minus the relative change in Q. From Dick and Marsalek's work we estimate, for the period 1926-1972, $dQ/Q = -.24$ (as given earlier) while the relative change in volume $dV/V = -.027$, or less than 3% (from $2.95 \times 10^8 \text{ m}^3$ to $2.87 \times 10^8 \text{ m}^3$; Dick and Marsalek p. 1). The net effect is therefore to increase the residence time by 21%. The change in residence time is dominated by the change in flow rate dQ/Q ; the relative change in volume dV/V is very small because most of the landfilling was carried out in shallow littoral areas where large losses of surface area result in only small losses in volume. A corollary is that there has been no change in volume to the deeper regions of the Lake.

If one considers the residence time of the hypolimnion alone, rather than that of the entire Harbour, it is clear that increases in residence time due to decreases in flushing flows are not offset at all by decreases in volume. Because of the way in which flushing occurs - first via the hypolimnion by underflow - it may be argued that the residence time of the hypolimnion is a more meaningful index for water quality than the residence time of the entire Lake. Using Dick and Marsalek's estimate for the inflow of $1.03 \times 10^9 \text{ m}^3/\text{year}$, assuming that all of this is used to flush the hypolimnion, and taking the volume of the hypolimnion as roughly one half the total lake volume (cf. Klapwijk and Snodgrass 1985) or $1.4 \times 10^8 \text{ m}^3$, gives a residence time for the hypolimnion of approximately 50 days.

The significance of the residence time becomes clear if one compares it with the time for oxygen depletion in the hypolimnion during summer stratification, a time which is on the order of a month or less (MOE 1985 ch. 6). Decreasing the flushing time to less than that of the oxygen decay time would prevent the occurrence of anoxia. Increasing the flushing time would further prolong the period of anoxia.

A further consequence of infilling shallow littoral areas is to reduce the net heat capture from the atmosphere by the epilimnion in summer. This in turn reduces the temperature (and hence density) differential between Harbour and Lake waters during summer. The net effect is to decrease exchange flows that are driven by density differences alone, as opposed to those driven by water level differences. It should be noted that Dick and Marsalek's model accounted only for flows driven by water level differences. Density driven flows can be considerable and the exchange rate is proportional to the square root of the density difference between the water at either end of the canal (Armi and Farmer 1986). The temperature stratified flows observed in the canal by Dick and Marsalek (Ch. 3), Kholi (1979), and others are probably driven by a combination of density and water level differences.

In summary, it is clear that the interactions of Harbour circulation and mixing with the exchange flows through the canal are complex. A better understanding of these processes is necessary if operational quantitative predictions of water quality are to be made.

IV.2.2 Sediment Quality

IV.2.2.1 General Description

Postglacial sediments in the Harbour are derived from tributaries, municipal and industrial discharges, and sewers. Settlement and urbanization have increased sediment loads, compared with presettlement conditions by increasing sediment production (e.g. construction and farming activity) and by altering basin hydrology (e.g. channelization, creation of impervious land surfaces).

Existing data (MOE, 1985; Poulton, 1986) suggest that a large zone of similar sediments covers the entire deep-water area of the Harbour except the far east end. Pollutants have been gradually mixed and transported towards the deep central basin. Other distinct zones occur near the Burlington Ship Canal, where the effects of Lake-Harbour exchange are important, and along the north shore, where shallow-water silty sediments of lower pollutant concentrations are found. Shallow locations close to the major outfalls represent individual zones related to the nearby discharges. The west end is distinct due to the influence of Cootes Paradise and Grindstone Creek. Most of the surficial sediments in Hamilton Harbour are gray to black, and rich in silt and clay. Sandy sediments are found along the north shore, near the Ship Canal, and at the entrance to Cootes Paradise.

Temporal trends in contaminant concentrations in surficial sediments (Table 7) are difficult to assess due to variations in sampling and analytical method-ologies. Available data are inconclusive as a means of tracking loadings reductions (suspended solids, nutrients, metals) at municipal and industrial discharges. Chemical analysis of sediment cores obtained at 22 locations throughout the Harbour during 1987 will assist in the interpretation of temporal trends. These data are not yet available.

Table 7: Trace metals in suspended solids and surficial sediments (1980 and 1986)

Metal	Suspended Particulates		Surficial Sediments	
	1982	1986	1980	1986
Iron mg/g	35	53	68	74
Manganese mg/g	20	9.6	1.9	2.1
Zinc μ g/g	1050	1797	2700	2180
Lead μ g/g	192	307	310	281
Copper μ g/g	103	105	130	158
Cadmium μ g/g	-	6.3	5.7	14.1
Nickel μ g/g	50	52	66	55

Sediment Sources

Annual suspended sediment loads to the Harbour were estimated to average 140,000 kg/day in 1977, diminishing to 66,100 kg/day by 1985 (MOE, 1985) and 50, 150 kg/day in 1987. This apparently large decrease will be confirmed during future investigations as part of a regular surveillance program.

The Ministry of Environment (West-Central Region) is carrying out a study to determine sources and loadings of suspended sediments and total phosphorus from tributary inputs to Hamilton Harbour. A weekly sampling program was initiated the week of June 16, 1987 at seven locations on five tributaries: Grindstone, Redhill, Spencer, Borer's and Indian/Rambo Creeks. Sampling will continue for at least one year.

A study will determine erosional areas and to estimate suspended sediment inputs from the various land uses in the basin. These two studies will allow the determination of existing suspended sediment loadings to the Harbour, the contribution of different land uses and the areas which are most prone to instream erosion. Abatement scenarios can then be determined.

IV.2.2.2 Sediment: Eutrophication-related conditions

Sediment sampling in the Harbour over the period 1975 to 1982 identified concentrations of nutrients throughout the Harbour which are higher than the disposal guidelines. Concentrations of nutrients (TP, TKN) have been found consistently above existing MOE guidelines for open water disposal of dredged material. Total Kjeldhal nitrogen and total phosphorus were 3.1 and 2.9 mg/g (Table 10). The loss on ignition of the surficial sediments from 1975 to 1980 was approximately 10% compared to the MOE guideline for disposal of sediments in the open Lake of 6%.

During the summer and fall, the low dissolved oxygen concentrations in the hypolimnion and the high organic loadings to the sediments result in low redox potentials within the

sediment. Manganese release from the sediments to the overlying water occurs frequently during summer and fall and iron release occurs less frequently towards the end of the summer. As a result of the reducing conditions, phosphorus release has been observed in the past. However, since the phosphorus appears to be associated with iron and the reducing conditions are not severe enough to release iron, phosphorus release from the sediments rarely occurs.

IV.2.2.3 Trace Contaminants

Persistent Organics

Sediment samples contain up to 2000 mg/Kg of organic solvent extractables (Mudroch and Sandilands 1980).

Elevated levels of PCBs have been observed in the sediments from Windermere Basin due to STP discharges and storm water discharges. Elevated PCB concentrations have also been observed along the north shore, particularly around the LaSalle Park Pier; the source is unknown. The mean concentration of PCBs in the Harbour sediments is 0.2-0.44 $\mu\text{g/g}$ (MOE, 1985;1986) which is within the range for sediments of other harbours on Lake Ontario (0.01 - 0.62 $\mu\text{g/g}$), but well above the levels in sediments offshore (0.058 $\mu\text{g/g}$). The MOE guidelines for open water disposal of sediments contaminated with PCBs is 0.05 $\mu\text{g PCBs/g}$. Some samples from the deepest areas and along the industrial shoreline exceeded 0.5 $\mu\text{g/g}$ (MOE 1986). In one study, the highest value (1.270 $\mu\text{g/g}$) occurred near the Burlington shoreline, and the lowest value was in Windermere Basin (MOE, 1986). In other studies, the concentration of PCBs in Windermere basin was 10 $\mu\text{g/g}$ (MOE, 1976) and 1 $\mu\text{g/g}$ (MOE, 1982). The distribution of PCBs is highly variable and the apparent random distribution is not yet understood, although seasonal variability associated with resuspension events may be involved.

Non-point sources such as atmospheric deposition and urban runoff via tributaries and storm sewers are likely to be significant sources of organic contaminants such as pesticides in Hamilton Harbour since point sources for these compounds do not exist in the watershed.

The distribution of PAHs indicates that the steel mills were the main source and that the Hamilton STP was a minor source (MOE, 1986). Concentrations of 14 PAH compounds measured in 1985 at 20 stations (Figure 7) varied from 0.01 to 466 $\mu\text{g/g}$ (Table 8). Total PAHs at each station ranged from 18 $\mu\text{g/g}$ at a station along the north shore of the Harbour, to 835 $\mu\text{g/g}$ at a station to the west of the Stelco docks. Nineteen PAH compounds have been detected in the point source loadings.

Figure 7
HAMILTON HARBOUR SEDIMENT SAMPLING LOCATIONS

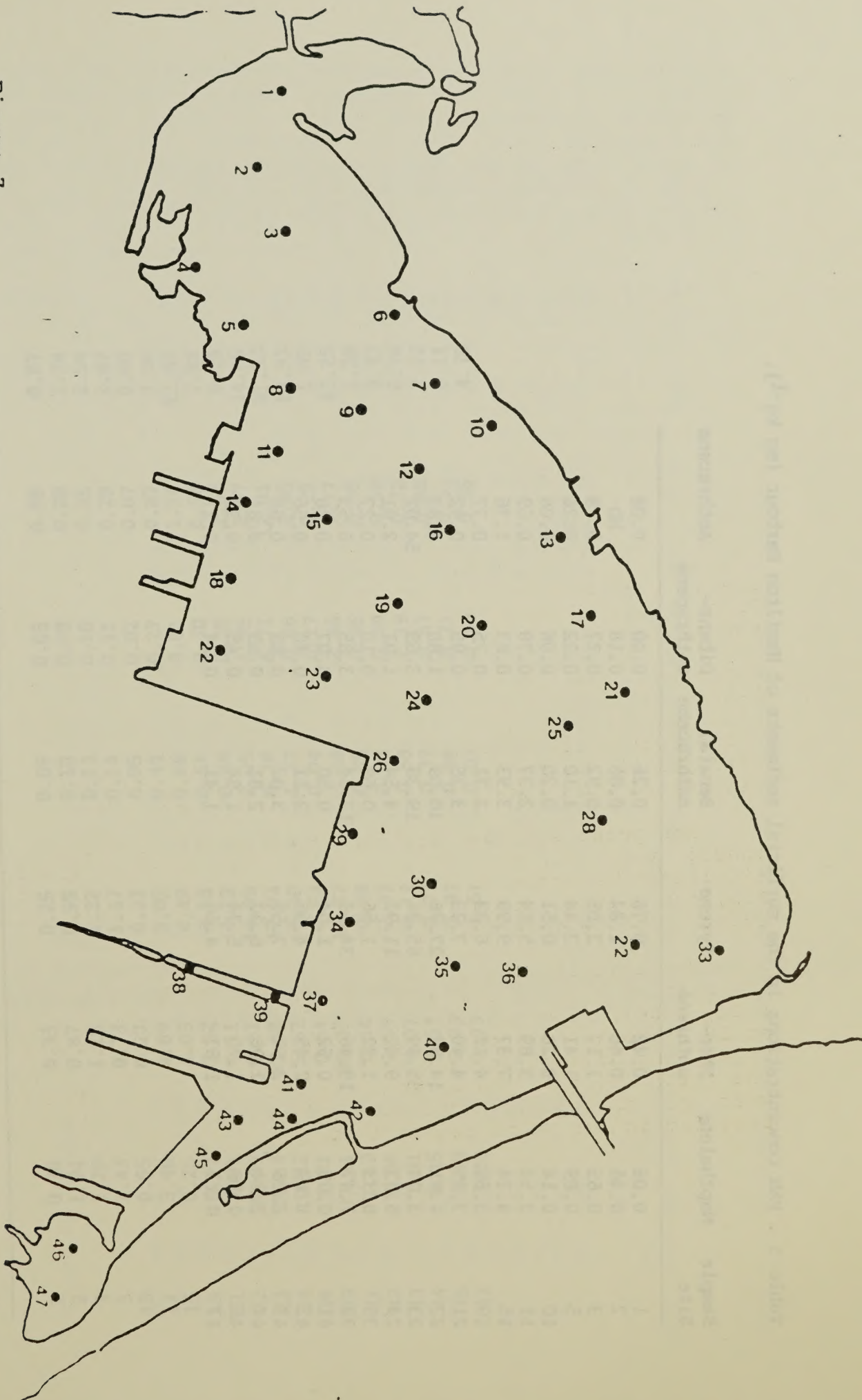


Table 3 . PAH concentrations in the surficial sediments of Hamilton Harbour (mg kg⁻¹).

Sample Site	Napthalene	Phen-anthrene	Pyrene	Benz(a) anthracene	Dibenz-anthracene	Anthracene
1	0.08	0.42	0.76	0.26	0.08	0.08
2	0.46	0.46	1.84	0.86	0.18	ND
3	0.65	1.17	2.05	0.92	0.27	0.18
5	0.89	1.41	2.44	1.10	0.22	0.26
10	0.14	0.28	0.51	0.20	0.06	0.06
11	2.54	3.89	5.64	2.37	0.79	0.69
15	4.24	7.37	9.99	3.93	0.83	1.36
19	3.58	4.12	6.33	2.71	0.75	0.77
21	3.35	4.40	7.23	3.25	0.99	0.92
22	4.91	14.87	27.76	10.09	1.80	4.83
23	3.04	55.39	65.31	19.39	3.69	54.02
24	5.83	9.42	11.92	4.54	1.01	2.01
36	0.33	1.32	1.56	0.69	0.10	0.27
39	7.47	15.46.	34.53	17.44	3.85	6.53
41	0.05	0.52	1.04	0.50	0.07	0.20
42	1.19	2.45	4.65	2.11	0.40	0.56
43	2.26	2.57	7.59	3.03	0.86	0.66
44	2.24	2.96	6.22	2.81	0.65	0.81
46	0.16	1.70	5.74	1.94	0.45	0.33
47	0.13	1.53 "	4.60	1.41	0.24	0.27

Table 3 . (cont'd) PAH concentrations in the surficial sediments of Hamilton Harbour (mg kg⁻¹).

Sample site	Benz(b) fluoranthene	Benzo(a) pyrene	Benz(ghi) perylene	Acenaphthylene	Acenaphthene	Fluorene	Fluoranthene
1	0.78	0.33	0.25	0.03	0.05	0.08	0.87
2	1.94	0.87	0.95	0.10	0.09	0.20	2.24
3	2.29	1.16	1.22	0.13	0.10	0.25	2.54
5	1.43	0.73	1.37	0.14	0.11	0.29	2.97
10	0.55	0.27	0.27	0.05	0.02	0.07	0.60
11	5.46	2.89	3.02	0.44	0.27	0.87	7.06
15	8.25	4.05	4.49	0.86	0.81	1.54	12.61
19	6.77	3.52	3.58	0.54	0.30	0.96	7.88
21	7.93	4.11	4.12	0.54	0.39	1.07	9.39
22	20.99	0.51	14.89	2.05	1.35	2.87	34.85
23	29.63	17.88	17.03	6.28	6.71	12.01	81.33
24	10.32	5.62	5.30	1.72	0.86	2.45	14.93
36	1.21	0.64	0.53	0.04	0.17	0.29	1.85
39	37.11	20.23	14.87	3.68	2.88	7.77	43.25
41	1.19	0.64	0.39	0.05	0.06	0.08	1.28
42	4.86	2.59	2.33	0.33	0.40	0.59	5.47
43	7.91	4.07	4.12	0.58	1.19	0.72	8.76
44	6.85	3.57	2.77	0.37	0.87	0.88	7.12
46	4.19	2.23	2.92	0.06	0.21	0.53	6.11
47	3.38	1.73	1.51	0.07	0.16	0.36	4.70

Table 2 Chlorinated organics in Hamilton Harbour sediment (mg kg⁻¹ dry wt).

Site	Beta BHC	Heptachlor epoxide	Beta chlordane	Alpha chlordane	pdDE	Dieldrin	Endrin	TDE	odDT	pDDT	Mirex	PCB
1	ND	ND	ND	ND	0.009	0.005	ND	0.009	ND	0.009	ND	0.142
2	ND	ND	0.012	ND	0.012	ND	ND	0.012	ND	ND	ND	0.316
3	ND	ND	0.011	ND	0.015	ND	ND	0.010	ND	ND	ND	0.365
5	ND	ND	0.009	ND	0.013	ND	ND	0.009	ND	ND	ND	0.376
10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.124
11	ND	ND	ND	ND	0.019	ND	ND	0.019	ND	ND	ND	0.547
15	ND	ND	ND	ND	0.022	ND	ND	0.016	ND	ND	ND	0.827
19	ND	ND	ND	ND	0.018	ND	ND	0.014	ND	ND	ND	0.622
21	ND	ND	ND	ND	0.025	ND	ND	0.015	ND	ND	ND	0.768
22	ND	ND	ND	ND	0.014	0.009	ND	0.009	ND	0.026	ND	0.467
23	ND	ND	ND	ND	0.007	ND	ND	0.007	ND	0.037	ND	0.154
24	ND	ND	ND	ND	0.022	ND	ND	0.017	ND	ND	ND	0.391
36	ND	ND	0.006	ND	0.008	ND	ND	0.012	0.004	ND	ND	0.231
39	ND	ND	ND	ND	0.011	0.011	ND	0.037	ND	0.077	ND	0.458
41	ND	ND	ND	ND	ND	ND	ND	ND	0.005	ND	ND	0.166
42	ND	ND	ND	0.014	0.025	ND	ND	0.011	ND	0.022	ND	0.638
43	ND	ND	ND	0.006	0.026	ND	ND	0.009	ND	0.026	ND	0.860
44	ND	ND	ND	ND	0.025	ND	ND	0.006	ND	0.022	ND	0.814
45	ND	ND	ND	0.014	0.031	0.010	ND	0.010	ND	0.034	ND	0.777
47	ND	ND	ND	0.012	0.036	0.009	ND	0.009	ND	0.023	ND	1.296

ND Non-detectable

The levels of pesticides in sediments are low. DDT averages about 0.006 $\mu\text{g/g}$ dry weight compared to 0.002 - 0.03 $\mu\text{g/g}$ in other Lake Ontario harbours. The most frequently occurring pesticides were α - and β -chlordane (5 and 7 ng/g respectively) and α -hexachlorocyclohexane (α -BHC, 2 ng/g) which were found in 1/2 to 2/3 of all samples. HCB (<1 ng/g), op-DDT (<5 ng/g), pp-DDE (<1 ng/g), and β -BHC were found in 15-25% of the samples (MOE, 1986). Organochlorine concentrations in the Harbour's sediments are illustrated in Table 9.

Metals

Metal levels in the surficial sediments from six stations from 1975 to 1986 and the guidelines for open-water disposal of dredged material are presented in Table 10.

Table 10: Summary of Surficial Sediment, Chemistry ($\mu\text{g/g}$)							
	1975	1976	1977	1977	1980	1986	Disposal Guideline
LOI (%)	10.5		9.1	9.5	9.8		6
BOD (mg/g)	3.9		2.6				
SOD (mg/g)	152	140	150	150			50
NH ₃			30	10			100
TKN (mg/g)	3.5	2.7	2.9	2.9	3.5		2
TP (mg/g)	3.4	2.4	2.7	2.9	3.2		1
Ether Ext. (mg/g)			12.5	7.6			1.5
Fe (mg/g)	68	70	88		68	74	10
Cu	101			110	130	158	25
Cr	206	200		220	204		25
Ni	45	39		52	44	55	25
Zn	3110	2010	2600		2700	2180	100
Pb	320	260	310	300	310	281	50
Cd	7.8	5.0		6.3	5.7	14.1	1
Mn	1670				1900	2100	-
Hg	2.4 ¹	0.4	0.7	0.6	0.3	2.0 ²	0.3
Co	15			12	10	20	50
As			19	22		40	8

1 Randles Reef
2 Lax property

Table 11 illustrates the spatial variability in trace metal concentrations in the Harbour's sediments (Station locations, Figure 7).

Table 11
Concentration ($\mu\text{g/g}$ dry weight) Of Minor Elements In Hamilton Harbour
Sediments

Site	Ni	Co	Cr	V	Cu	Pb	Zn	As
1	25	10	33	30	27	57	252	3
2	46	29	110	67	91	165	1610	16
3	49	19	140	76	102	215	2270	18
4	53	20	158	72	115	280	2600	23
5	52	24	160	76	110	265	2740	16
6	48	17	160	64	89	245	2690	21
7	31	12	66	27	23	79	950	7
8	42	20	130	67	86	195	1670	12
9	56	21	305	87	130	440	4400	27
0	49	15	150	51	64	195	2580	11
1	28	11	67	28	36	73	545	6
2	56	26	400	87	160	570	6000	28
3	53	22	335	78	113	360	4090	25
4	40	13	210	49	145	330	1695	12
5	57	21	290	87	131	400	3710	29
6	57	23	310	88	128	430	3450	29
7	60	20	320	84	129	400	3500	30
8	30	8	125	26	39	110	645	4
9	56	21	325	89	136	470	4210	33
0	56	17	400	91	149	690	6630	46
1	60	21	310	82	130	390	3470	36
2	34	13	125	45	95	150	1660	10
3	47	18	200	73	95	270	2190	24
4	53	21	360	79	140	470	5080	39
5	55	25	480	90	155	550	6060	40
6	51	23	420	80	132	430	4780	30
7	53	21	360	82	155	470	5360	38
8	53	21	360	79	158	370	3991	25
9	25	17	103	27	21	34	273	4
0	51	18	360	80	137	360	3620	25
1	53	19	400	92	155	400	4400	36
2	48	16	280	73	125	265	2910	23
3	27	11	43	36	22	36	305	2
4	32	12	145	49	58	140	1330	8
5	41	18	170	57	92	185	1850	15
6	36	15	120	51	48	88	745	14
7	37	12	490	29	85	430	3270	33
8	37	4	475	41	104	370	2960	34
9	47	4	385	75	124	325	2930	23
0	48	20	295	83	131	340	2740	29
1	39	15	98	62	136	200	1610	18
2	41	16	103	79	102	245	1820	15
3	37	14	220	54	94	200	1750	12
4	37	13	290	63	100	220	3150	13
5	49	18	400	70	160	350	2030	5
6	47	18	170	66	107	170	590	2
7	56	25	305	72	138	205	815	12

Lum and coworkers (McIsaac et al., 1981) found that the most important chemical phase for metals was the iron-manganese oxides. These oxides controlled the solubility of manganese, zinc, and occasionally lead. These elements can be released into solution and become more bioavailable and toxic if the water becomes anoxic. Most of the copper was associated with organic matter; chromium, lead, nickel and zinc were often associated with organic matter as well (McIsaac et al., 1981). In many samples, a large portion of the metals was refractory; thus, the metals were not bioavailable or toxic. Mudroch (1980) found that cadmium, chromium, mercury, and arsenic were not released into solution when sediment samples were shaken with lake water.

With the exception of the area near the Dundas STP, the concentration of metals in most of Cootes Paradise is much lower than in Hamilton Harbour. Concentrations of zinc, lead, and copper are 1/8, 1/5, and 1/2 respectively, of the Harbour sediments (MOE, 1975; 1977). Moreover, the concentrations of zinc, copper, lead and cadmium in the surface sediment near the outlet of Cootes Paradise decreased greatly from 1975 to 1980 (MOE, 1986). The improvements to the Dundas STP are responsible for the improvements in water quality and presumably the sediments of Cootes Paradise.

IV.2.2.4 Dredging Operations

Dredging activity in the Harbour has gradually diminished since the late 1950s. Annual maintenance dredging, which is the responsibility of Public Works Canada has removed a total of 341,573 m³ since 1980 although it has not been conducted on an annual basis. Capital dredging projects are undertaken by the Hamilton Harbour Commission approximately once every five years. Most of the recent activity has been in the approach channel and turning basin to the Dofasco and Strathearne Avenue slips. In addition, some slips, which had been dredged regularly in the past, are slowly being filled in to form piers. No dredging has been necessary in the Harbour since 1984.

Since 1970, disposal of the dredged material has been confined to prevent the entry of pollutants back into the watercourse. Therefore, the dredging and disposal operations are felt to have little negative effect on water chemistry and sediment chemistry. The dredging operations are removing contaminated sediments and therefore could be viewed as improving the Harbour sediment contaminant conditions. However, the amount of sediment dredged during the past decade relative to the total amount of contaminated sediment in the Harbour is minor.

IV.2.3 Biology

IV.2.3.1 Bacteria

Coliforms (Objectives for Swimming)

Bacterial counts are higher in the south and east areas of the Harbour compared to the north and west. Fecal coliform counts recorded in the past year (1986-87) indicate moderate increases over those of a decade earlier. Mean fecal coliform counts based on just six samples for each station all exceeded the level set for swimming (100/100 ml). More intensive sampling would be required to reliably test the suitability of Hamilton Harbour for body contact recreation. The geometric mean fecal coliform counts (#'s/100 ml) were 114 and 175 at stations #270 and #258, respectively. During the past decade, more frequent sampling has been conducted at the central (#258) and western (#270) stations and the fecal coliforms have consistently been below the objective for swimming (geometric mean= 57/100ml). Climatic conditions in 1987 (dry and hot) may have been responsible for the elevated fecal coliform counts.

Total coliforms were not determined in 1987. Previous estimates from 1975 indicate that the Harbour exceeds the total coliform objective for swimming (1000/100ml). The geometric mean for stations #270 and #258 for 1975 was 1475/100ml. The south and eastern areas of the Harbour had higher levels of total coliforms.

Chemical cycles

Annual, Harbour-wide geometric mean densities of sulphur oxidizing bacteria have changed dramatically, but irregularly, since 1975. This suggests that the significance of these bacteria and the sulphur oxidizing processes to oxygen depletion may be quite variable from year to year. In general, densities decrease with depth and from the eastern to the western end of the Harbour. This suggests a strong link between bacterial numbers and the point source inputs. The last source of reduced sulphur was eliminated in 1984, and therefore, sulphur oxidation is probably no longer important in the Harbour.

Nitrification is a two step bacterially mediated process which converts ammonia (NH_3) to nitrate (NO_3): first, ammonia to nitrite by Nitrosomonas; and then, nitrite to nitrate by Nitrobacter. Nitrification requires oxygen for the conversion of ammonia (NH_3) to nitrate (NO_3). The seasonal contribution of nitrification to the total water column oxygen demand ranges from 10% to 45%. Population densities of nitrifiers show extremely high fluctuations not just seasonally, but also on a weekly basis. The presence of significant concentrations of ammonia in the Harbour throughout the year indicates that these bacteria are not substrate limited. Populations of nitrifiers were highest in the west end of the Harbour which is geographically distant from the point source loadings of ammonia.

Heterotrophs are a heterogeneous group of organisms requiring organic carbon for growth and oxygen for metabolic processes. Densities are greatest in the eastern end of the Harbour. Levels are elevated in the surface waters where temperature, dissolved oxygen, algal biomass and dissolved organic carbon concentrations are the highest. The numbers of heterotrophic bacteria are greatest in the spring and autumn, followed by the winter and finally the summer, suggesting that densities are not strictly controlled by temperature. In addition, the presence of high concentrations of dissolved organic carbon throughout the year would suggest that they are not substrate limited. The major factor limiting growth and metabolic activity during the summer would appear to be low dissolved oxygen concentrations.

IV 2.3.2 Benthos

Johnson and Matheson (1968) sampled the benthic community of Hamilton Harbour in 1964. Their results indicated a severely degraded ecosystem dominated by pollution-tolerant oligochaetes (worms). Limnodrillus hoffmeisteri occurred at all of the sites sampled and represented 50% of the total mature population of oligochaetes. Tubifex tubifex was found at 85% of the sites and contributed 30% to the population. More sensitive species such as Quistadrillus multisetosus made up less than 5% of the population and occurred at less than 30% of the sample sites. Oligochaete abundance was highest in the area adjacent to the Burlington Ship Canal suggesting a positive effect of Lake Ontario on Hamilton Harbour water and/or sediment quality. Low abundance in the rest of the Harbour, particularly in a 2 km² "toxic zone" close to the Ottawa Street slip, supported the hypothesis that poor water quality and/or sediment toxicity was inhibiting the abundance and distribution of oligochaetes in the Harbour. Four genera of chironomids were reported in the Harbour in 1964.

The Harbour was resampled in 1984 to determine the response of the benthic community to remedial actions implemented between 1964 and 1984. The Harbour was dominated by oligochaetes. Abundance ranged from absent at the south end of the Ottawa St. slip to 450,000 m⁻² in Windermere Basin and in the deep central basin. Average biomass was between 10,000 and 100,000 oligochaetes m⁻² (Figure 8). Quistadrillus multisetosus, a pollution-sensitive oligochaete was 42% of the total benthic invertebrate population. Limnodrillus hoffmeisteri and Tubifex tubifex, pollution-tolerant oligochaetes, were 32 and 10% of the population. Chironomids were present at all of the littoral sites sampled. Mean abundance at the littoral sites was 302 m⁻². Visual surveys conducted in 1988 indicate the presence of extensive clam beds in the shallow water between LaSalle Marina and the north east corner of the Harbour.

1964

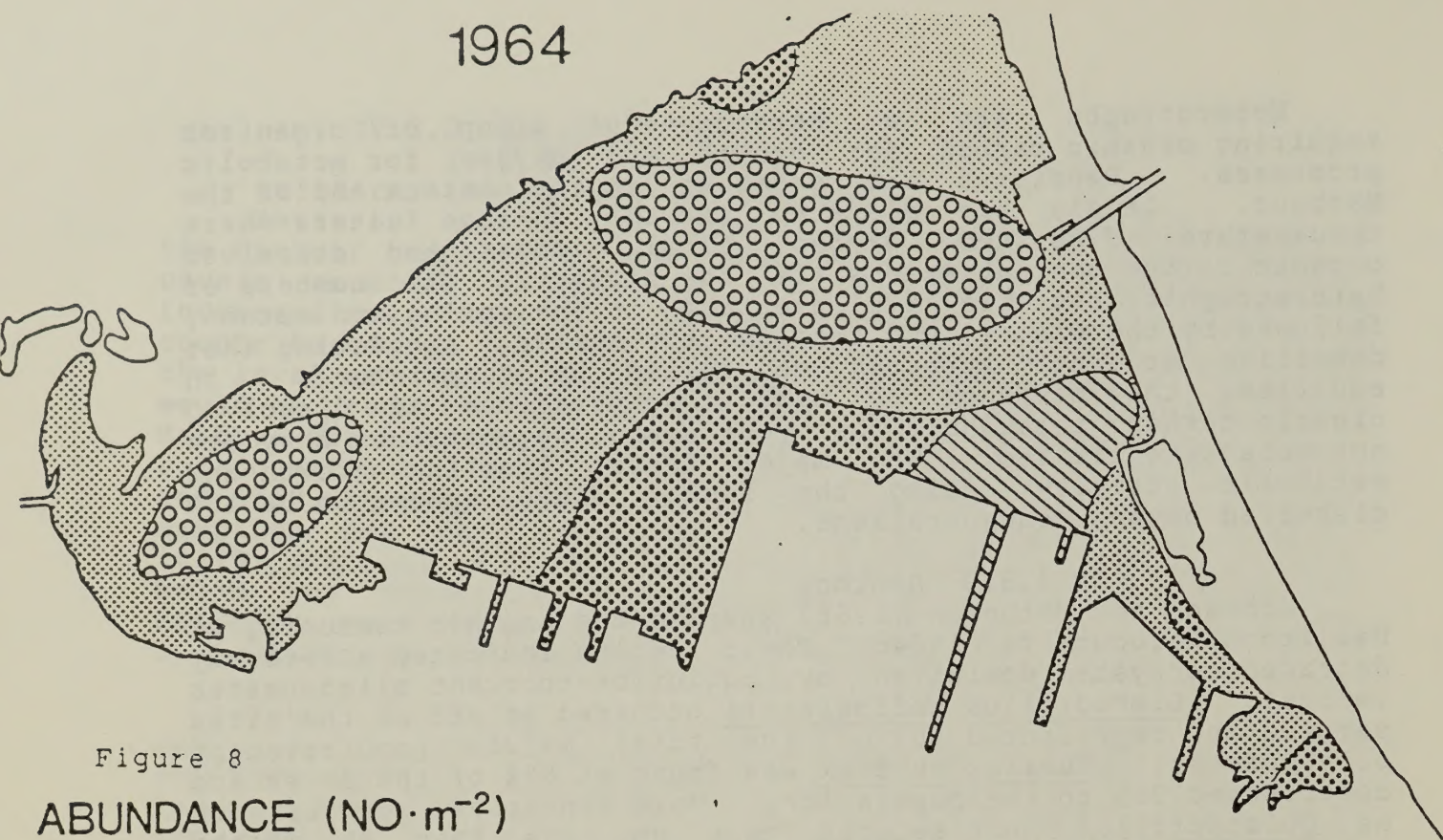
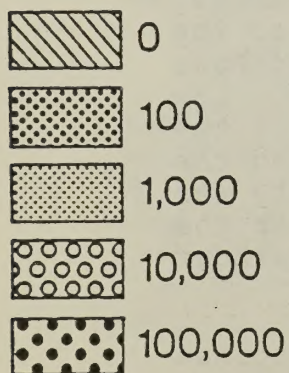
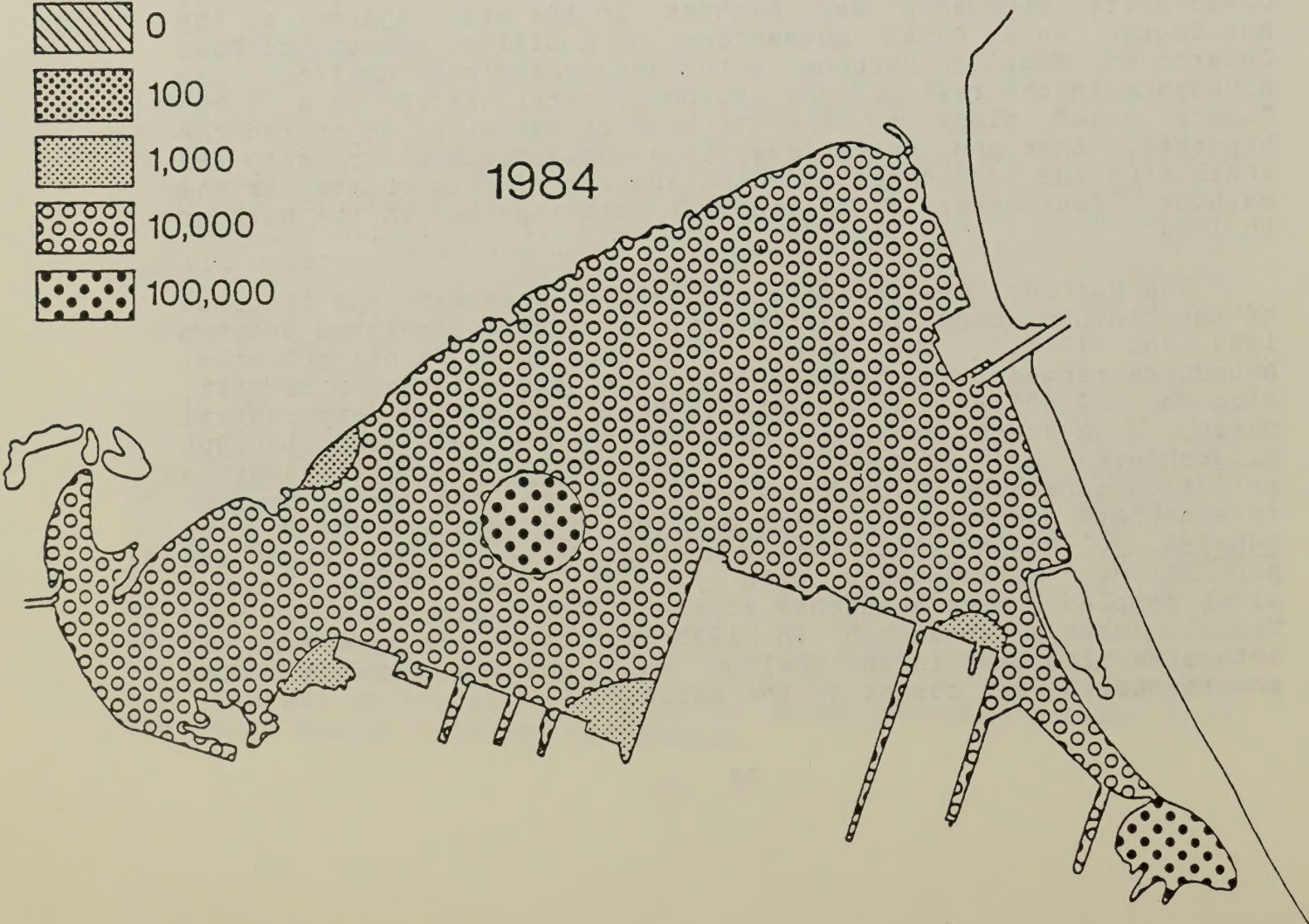


Figure 8

ABUNDANCE ($\text{NO} \cdot \text{m}^{-2}$)



1984



Although the benthic community in Hamilton Harbour is indicative of a highly eutrophic environment, substantial improvements have occurred in the abundance and community composition since 1964. The "toxic zone" described in 1964 has been reduced from 2 km² to a small area at the south end of the Ottawa St. slip. Biomass throughout the Harbour has increased between 5 and 20 fold and the community composition has shifted away from pollution-tolerant species towards more pollution-sensitive species. An additional four genera of chironomids were found in 1984. Sphaerids, which were not found in the 1964 survey, occurred in 11 sites in 1984.

IV.2.3.3 Phytoplankton

The production of organic carbon by phytoplankton in the Harbour is up to 1.5 times greater than the organic carbon loadings from municipal and industrial sources (MOE, 1985). Much of this algal biomass settles into the hypolimnion where it decays and consumes oxygen. Together with ammonia oxidation, the oxidation of decaying algae can keep the hypolimnion anoxic (MOE, 1985).

The algal biomass in the Harbour is lower than would be expected from nutrient loadings alone (Haffner et al. 1980). Although Haffner proposed that physical factors regulate phytoplankton growth, others have thought that toxic compounds may inhibit algae. Algae isolated from Hamilton Harbour were not affected by zinc concentrations two orders of magnitude higher than observed in the Harbour (Piccinin, 1977). Wong et al. (1978) found that mixtures of metals in concentrations equivalent to the water quality Objectives were inhibitory to four species of algae. The metal concentrations ($\mu\text{g/l}$) used were: arsenic 50; cadmium 0.2; chromium 50; copper 5; iron 300; lead 25; mercury 0.2; nickel 25; selenium 10; and zinc 30. Current metal concentrations ($\mu\text{g/l}$) in Hamilton Harbour are: arsenic ND; cadmium ND; chromium 2; copper 3; iron 191; lead ND; mercury ND; nickel 4; selenium 1; and zinc 17. Goudey (1983) found that copper and mercury at concentrations found in the Harbour could inhibit photosynthesis; but again, metal concentrations have decreased since Goudey did his study. Metals are largely detoxified by precipitation and adsorption to cell debris (Goudey 1983). Moreover, some Harbour algae (Scenedesmus and Coelastrum) are more tolerant to copper and zinc than are similar laboratory strains (Goudey, 1983).

Physical factors are felt to be more important in restricting algal growth. Light limitation by coloured organic material (Harris, 1976; Harris et al. 1980) and self-shading (Harris, 1976) is a major factor regulating macrophyte and phytoplankton growth. Light limitation favours the growth of larger algae which can optimize light utilization (Harris, 1976; Piccinin, 1979).

Phytoplankton are sensitive to rapid fluctuations in light regime, such as those brought about by turbulence in the mixed layer (Harris et al., 1980). Incursions of Lake Ontario water through the Ship Canal, and direct wind stirring cause vertical mixing and rapid changes in mixing depth.

Phytoplankton are adaptable to fluctuations in the ratio of light penetration to mixing depth (Z_{eu}/Z_m) (Haffner et al., 1980). Physiological adaptations such as altered chlorophyll content or photosynthetic enzymes are seen during the summer in green algae. Some species, such as Cryptomonas, utilize heterotrophic processes rather than relying on photosynthetic carbon uptake. Small coccoid cells such as Chlamydomonas lose their flagella and pigment as the ratio of light penetration to mixing depth decreases and cells spend less time in the euphotic zone.

During periods of stable light and mixing depth, large cells such as Oocystis borgei predominate (Haffner et al., 1980). This species persisted in the summer once a thermal gradient was established, but declined when lake mixing increased (Haffner et al., 1980). Changes in the mixing depth can give the impression of multiple growth peaks. Near monospecific phytoplankton blooms occur most commonly under conditions of relatively stable physical parameters (Harris et al., 1980).

Diatom growth is related to vertical mixing. Without vertical turbulence, the heavy silica shells tend to sink out of the water column. The persistence of diatoms throughout the year is evidence of vertical turbulence during the stratified period (Haffner et al., 1980). The survival of Stephanodiscus also depends directly on its resuspension by vertical mixing (Klapwijk and Snodgrass, 1983).

Diatoms are favoured also, by the fact that they can utilize energy from green light more efficiently than can green algae. As green light penetrates water three times farther than blue light, diatoms are less stressed when light penetration is poor.

The seasonal succession of Hamilton Harbour phytoplankton includes diatoms and small phytoflagellates early in the year, during periods of homogeneous mixing. These are followed by the predomination of coccoid green algae for a short period of time, and then by a mixture of diatoms and green algae at the time when the maximum summer temperature is reached. Diatoms and flagellates later return as the dominant species. Blue-green algae are noticeably absent from the Harbour despite the eutrophic conditions (Harris and Piccinin, 1980).

Algal primary production is responsible for the fixation of 6.5 to 58 metric tonnes of organic carbon per day which is 0.2 to 1.7 times the estimated external load in 1979. In addition, 4.6

to 41 metric tonnes per day of organic nitrogen is similarly produced which is 0.2 to 1.6 times the estimated external load for 1979. Both organic carbon and nitrogen are responsible for a significant portion of the oxygen demand in the Harbour and algal biomass is a major contributor to these reservoirs.

IV.2.3.4 Zooplankton

The few studies that have been done on Hamilton Harbour zooplankton communities have established that the zooplankton fauna is typical of a eutrophic lake where the food chain is largely based on detritus (Piccinin and Harris, 1980; Harris, 1976). Large rotifer populations exist in the Harbour and dominate the zooplankton community for most of the year. A cladoceran, Bosmina longirostris, is also common at certain times of the year, while some other cladoceran species (e.g. Daphnia) and copepods are less common than might be expected based on observations from other eutrophic lakes.

The seasonal succession of zooplankton in Hamilton Harbour includes an early spring peak made up almost entirely of the rotifer Keratella quadrata (Harris, 1976). During summer in the stratified Harbour, epilimnetic species are dominated by Bosmina longirostris and Brachionus angularis. Few species can survive in the anoxic bottom layers. During fall turnover, zooplankton numbers increase as hypolimnetic reoxygenation opens up new habitats. Piccinin and Harris (1980) have found Bosmina abundance to be positively correlated to oxygen tension during the summer. In 1976, MOE aerated two sites in the Harbour, creating an oxic hypolimnion, leading to an increased zooplankton biomass when compared to the previous year (Piccinin, 1977).

Zooplankton biomass has been positively correlated to phytoplankton biomass in the epilimnion of Hamilton Harbour (Harris, 1976). Fluctuations in zooplankton numbers and dry weights were found to correspond to changing phytoplankton biomass, and to the thermal structure of the water. Grazing, however, had little effect on total algal biomass (Harris 1976). It is believed that the zooplankton in the Harbour feed mostly on bacteria and detritus (Piccinin and Harris, 1980).

Rotifer distribution was shown to be associated with both seasonal and depth components (Piccinin and Harris, 1980). Rotifer abundance was correlated with ammonia and silica distribution which vary with the season and with depth. Rotifers generally occur throughout the entire water column.

IV.2.3.5 Macrophytes

Cootes Paradise

The wetland vegetation of Cootes Paradise and Hendrie Valley/Carroll's Point area is currently dominated by a small number of hardy emergent species such as manna grass, cattail and giant burreed (S. eurycarpum). There are still small localized

stands of bulrush (*Scirpus* spp.) and sedges (*Carex* spp) in the more protected inlets which fringe the basin. The present extent of emergent vegetation is approximately 15% of the total area. The emergent vegetation is restricted to areas above the normal high water level. The open water area of Cootes Paradise measures 250 hectares and is virtually devoid of aquatic plants.

Submergent communities are dominated by a small number of hardy species namely sago pondweed (*Potamogeton pectinatus*). Table 12 shows four time periods and the changes in community composition.

Table 12
Checklist of Submergent Aquatic Plants in Cootes Paradise

Species	1946-48	1968-72	1985	1987
<i>Potamogeton berchtoldii</i>	1	-	-	
<i>P. crispis</i>	2	2	1	
<i>P. foliosus</i> var. <i>macellus</i>	1	-	-	
<i>P. natans</i>	1	-	-	
<i>P. nodosus</i>	2	1	1	
<i>P. pectinatus</i>	2	3	3	2
<i>P. perfoliatus</i>	1	-	-	
<i>P. zosteriformis</i>	2	-	-	
<i>Najas flexilis</i>	1	-	-	
<i>Elodea canadensis</i>	2	1	1	
<i>Spirodela polyrhiza</i>	1	1	1	
<i>Lemna minor</i>	3	3	3	2
<i>L. trisulca</i>	1	-	1	
<i>Wolffia columbiana</i>	1	1	1	
<i>W. punctata</i>	1	-	-	
<i>Polygonum amphibium</i> var <i>stipulaceum</i>	2	-	-	
<i>Ceratophyllum demersum</i>	3	2	1	
<i>Nuphar advena</i>	3	-	-	
<i>N. variegatum</i>	3	2	2	2
<i>Nymphaea odorata</i>	3	-	-	
<i>N. tuberosa</i>	3	3	2	2
<i>Myriophyllum verticillatum</i> var <i>punctatum</i>	3	-	-	
<i>Utricularia vulgaris</i>	3	1	-	
<i>Megalondonta beckii</i>	1	-	-	
	25	11	11	4

Key: 3 - plants in large numbers and dominant at few or many sites
 2 - plants which are not dominant but which are occasionally or frequently encountered
 1 - not common or dominant
 - - not encountered

Hamilton Harbour

The distribution and relative abundance of submerged vegetation was determined during 1987 from echosounding along the 1.3 m contour of the Harbour. Twenty-two transects perpendicular to shore were used to establish the maximum depth of macrophyte growth. Plants were rarely found at depths greater than 2 m. The extent of littoral zone colonized by submerged plants was determined by measuring the area between the shore and the 2m contour. However, plants rarely grew at depths less than 0.5 m and this method slightly overestimated the distribution of aquatic vegetation in the Harbour. Echolocating was used initially to identify areas of dense, heavy, moderate, and sparse vegetation. Species richness and density (number of plants/m²) in these sites were subsequently measured by direct observation (SCUBA) at three locations in each vegetation type.

There are 199 ha of littoral habitat (less than 2 m deep) remaining in Hamilton Harbour. Only 45 percent of the total littoral area contained moderate to dense vegetation (Table 13). Plant abundance in the remaining 55 percent of the littoral zone ranged from absent to sparse (3 plants/m²). Submerged vegetation was confined to the north shore and to the west shore of the Harbour between the former Lax property and the Desjardins Canal (Figure 9). Plants did not grow at depths greater than 2.5 m, probably due to poor light penetration below that depth. Plants were absent along the south shore east of the Royal Hamilton Yacht club. The littoral zone along the east shore of the Harbour is shallow enough to permit vegetation but plant growth is limited by almost constant wave action and poor light penetration. Prior to 1985, the east shore, south of the Burlington Canal was moderately vegetated (V. Cairns pers comm). Shoreline restructuring to accommodate the West Service Road transformed this area into a high energy rubble shore that reflects wave action and inhibits plant growth.

TABLE 13

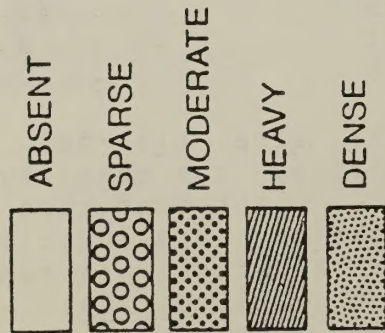
Submerged aquatic vegetation extent in Hamilton Harbour, 1987.

CATEGORY	AREA (ha)	# SPECIES	PLANTS/M ²
DENSE	16	1	400
MODERATE	74	5	63
SPARSE	79	1	3
ABSENT	30	0	0

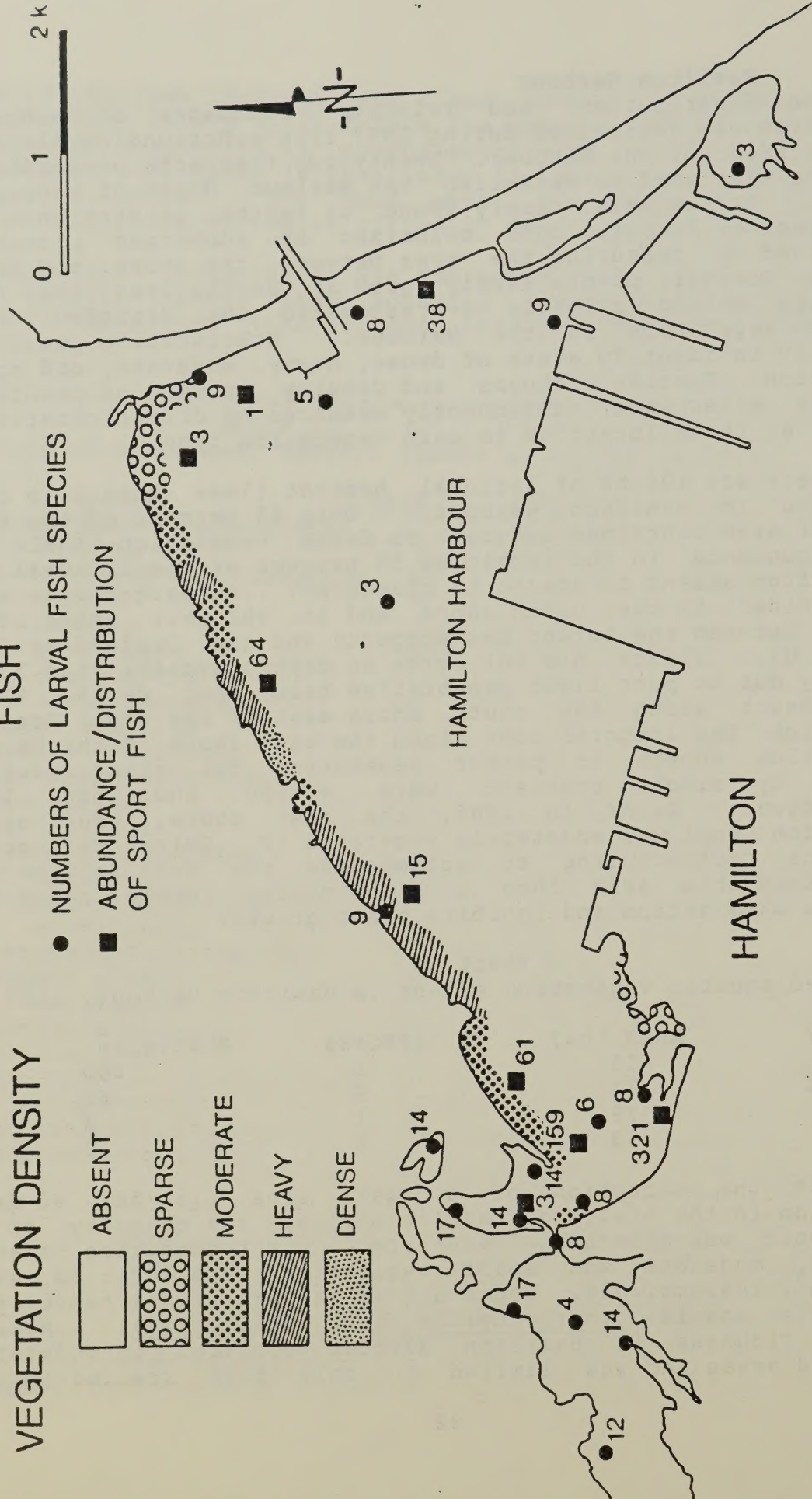
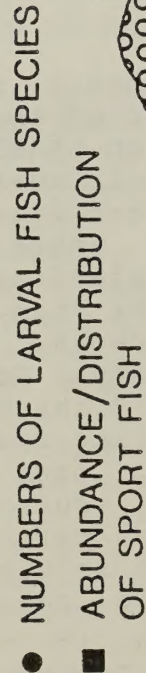
With the exception of a small area (16 ha) of dense vegetation in the sheltered LaSalle marina, the majority of the north shore was moderately vegetated. Plant densities in areas of dense, moderate, and sparse vegetation were 400, 63, and 3 plants/m², respectively. Dense and sparse areas were represented by single species (Myriophyllum and Vallisneria). Maximum species richness in Hamilton Harbour occurred in moderately vegetated areas and was limited to only five species (Elodea

Figure 9

VEGETATION DENSITY



FISH



canadensis, Vallisneria americana, Heteranthera dubia, Myriophyllum spicatum, and Potamogeton pectinatus). These plants are characteristic of eutrophic environments (Crowder and Bristow, 1986).

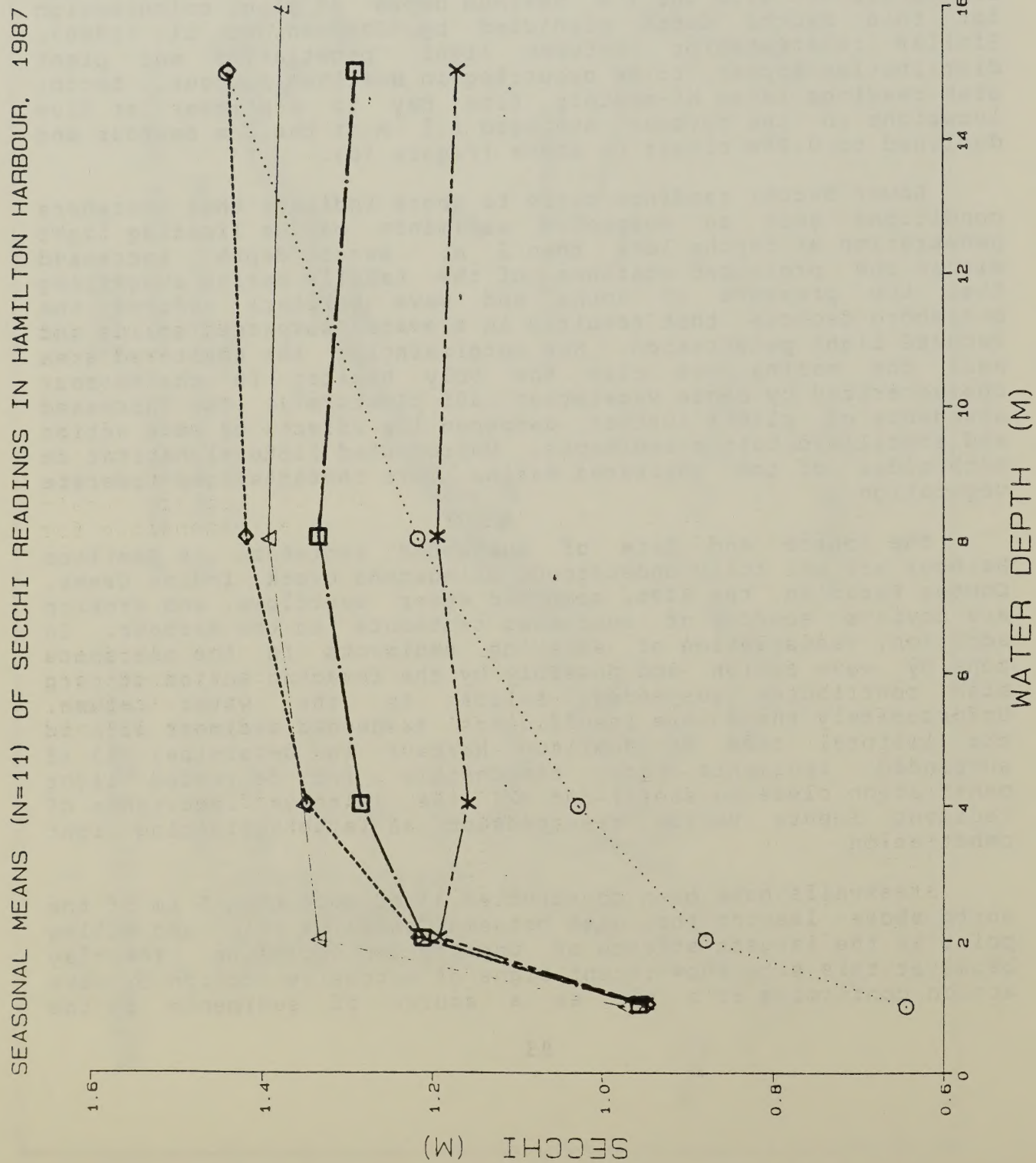
Crowder and Bristow (1986) reported that reduced light transparency was the most important factor limiting the distribution, abundance, and diversity of submerged aquatic plants in the Bay of Quinte. Secchi disk readings averaged 1.2 m in the Bay of Quinte and submerged vegetation did not grow at depths greater than 2 m (Crowder and Bristow, 1987). These data are consistent with the 2 m maximum depth of plant colonization for this Secchi depth predicted by Chapman et al. (1986). Similar relationships between light penetration and plant distribution appear to be occurring in Hamilton Harbour. Secchi disk readings taken bi-monthly from May to September at five locations in the Harbour averaged 1.2 m at the 2 m contour and declined to 0.95m closer to shore (Figure 10).

Lower Secchi readings close to shore indicate that nearshore conditions such as suspended sediments may be limiting light penetration at depths less than 2 m. Secchi depth increased within the protected confines of the LaSalle Marina suggesting that the presence of docks and wave barriers reduced the nearshore factors that resulted in elevated suspended solids and reduced light penetration. Not surprisingly, the sheltered area near the marina was also the only habitat in the Harbour characterized by dense vegetation (400 plants/m²). The increased abundance of plants further dampened the effects of wave action and stabilized bottom sediments. Unprotected littoral habitat on both sides of the sheltered marina were characterized moderate vegetation.

The source and fate of suspended sediments in Hamilton Harbour are not fully understood. Grindstone Creek, Indian Creek, Cootes Paradise, the STPs, combined sewer overflows, and erosion are obvious sources of suspended sediments to the Harbour. In addition, resuspension of existing sediments in the nearshore zone by wave action and possibly by the foraging action of carp also contributes suspended solids to the water column. Unfortunately there are insufficient suspended sediment data in the littoral zone of Hamilton Harbour to determine: 1) if suspended sediments are responsible for decreased light penetration close to shore; and 2) the relative importance of sediment inputs versus resuspension as factors limiting light penetration.

Breakwalls have been constructed along more than 5 km of the north shore leaving the area between Carroll's Point and Willow point as the largest stretch of unprotected shoreline. The clay banks at this site show recent signs of extensive erosion by wave action confirming it's role as a source of sediments to the

Figure 10



Harbour. Although erosion along the north shore is minimized by the breakwalls, the restructured concrete shore reflects wave energy back into the littoral zone and increases sediment resuspension. The combination of reduced light penetration and unstable substrate limits plant abundance and distribution. It also reduces the diversity and abundance of benthic invertebrates and fish.

Light penetration is severely limited in Cootes Paradise and the mouth of Grindstone Creek. Secchi depths at these sites ranged from 14 to 38 cm throughout the summer of 1985 (Portt et al. 1986). Suspended sediments frequently exceed 80 mg/l (McLarty, 1986) and appear to be the most important factor limiting light penetration. The absence of plants in Cootes Paradise to consolidate and stabilize the fine silt/clay sediments facilitates wind generated sediment resuspension which further reduces the ability of plants to colonize Cootes. The contribution of carp to plant loss (from physical destruction and sediment resuspension resulting from benthic foraging) has not been quantified in Cootes or the Harbour. However, a carp removal study in Mercers Glen during 1987 showed that sediment resuspension by carp maintained poor water clarity in that small pond. (Painter, pers. comm.).

Sediment resuspension also appears to be responsible for reduced light penetration in the Grindstone Creek estuary. Suspended clay and silt transported by Grindstone Creek during erosion events is deposited in Sunfish Pond and in the Valley Inn road area. The mean depth at both sites is now less than .5 and 1 m, respectively. The creek, Sunfish Pond, and the estuary are turbid during periods of runoff. However, Grindstone Creek is clear during dry periods but Sunfish Pond and the estuary remain turbid suggesting that wind (and/or carp) are responsible for sediment resuspension.

IV.2.3.6 Fish

Larval Fish

Larval and juvenile fish surveys were conducted in 1985 and 1987 by the Department of Fisheries and Oceans in littoral and open water areas of both Hamilton Harbour and Cootes Paradise. Forty-two species of larval fish were identified (Table 15) and the most common larval fish are listed in Table 14.

Table 14: Larval Fish Composition, 1985 and 1987

Species	Percent Composition
Gizzard Shad	50%
Alewife	32%
Yellow Perch	5.1%
Bluegill	2.8%
Pumpkinseed	2.5%
White Perch	2.3%
Total	95%

Most species were caught in the west end of the Harbour and in Cootes Paradise (Figure 9).

Twenty-seven adult Northern Pike were observed in Grindstone Creek. Spawning was observed and pre and post spawning females and males were confirmed. Larval pike were not collected but this is normal since larval pike are particularly difficult to collect.

Adult Fish

The relative abundance (catch per unit effort) and distribution of fish in Hamilton Harbour were determined from gillnetting surveys conducted from September to December, 1984 and from April to September, 1985 (Portt and Cairns 1988). Additional data were obtained from an electrofishing survey of the Harbour by the OMNR in October, 1987.

Hamilton Harbour supports a diverse fishery represented by 19 families, 42 genera, and 59 species (Table 15). Although diversity is high, community structure has shifted from the larger, long-lived species common in the late 1800s to smaller, short-lived species characteristic of eutrophic environments.

Table 15

Fish species in Hamilton Harbour and Cootes Paradise 1984-87

Adults	Larvae
<i>Petromyzon marinus</i> - sea lamprey	
<i>Anguilla rostrata</i> - American eel	
<i>Lepisosteus osseus</i> - longnose gar	
<i>Amia calva</i> - bowfin	
<i>Alosa pseudoharengus</i> - alewife	*
<i>Dorosoma cepedianum</i> - gizzard shad	*
<i>Oncorhynchus kisutch</i> - coho salmon	*
<i>Oncorhynchus tshawytscha</i> - chinook salmon	*
<i>Salmo gairdneri</i> - rainbow trout	
<i>Salmo trutta</i> - brown trout	
<i>Salvelinus namaycush</i> - lake trout	
<i>Coregonus artedii</i> - lake herring	
<i>Couesius plumbeus</i> - lake chub	
<i>Osmerus mordax</i> - american smelt	*
<i>Umbra limi</i> - central mudminnow	*
<i>Esox lucius</i> - northern pike	
<i>Carassius auratus</i> - goldfish	*
<i>Cyprinus carpio</i> - carp	*
<i>Notemigonus crysoleucas</i> - golden shiner	*
<i>Notropis atherinoides</i> - emerald shiner	*
<i>Notropis hudsonius</i> - spottail shiner	*
<i>Notropis heterolepis</i> - blacknose shiner	*
<i>Notropis heterodon</i> - blackchin shiner	
<i>Notropis cornutus</i> - common shiner	*
<i>Notropis chrysocephalus</i> - striped shiner	*

<i>Notropis volucellus</i> - mimic shiner	*
<i>Pimephales promelas</i> - fathead minnow	*
<i>Pimephales notatus</i> - bluntnose minnow	*
<i>Semotilus atromaculatus</i> - creek chub	*
<i>Rhinichthys atratulus</i> - blacknose dace	*
<i>Carpionodes cyprinus</i> - quillback	
<i>Catostomus commersoni</i> - white sucker	*
<i>Catostomus catostomus</i> - longnose sucker	
<i>Hypentelium nigricans</i> - northern hog sucker	
<i>Ictiobus cyprinellus</i> - bigmouth buffalo	
<i>Ictalurus nebulosus</i> - brown bullhead	*
<i>Ictalurus punctatus</i> - channel catfish	*
<i>Ictalurus melas</i> - black bullhead	*
<i>Ictalurus natalis</i> - yellow bullhead	*
<i>Noturus gyrinus</i> - tadpole madtom	*
<i>Fundulus diaphanus</i> - banded killifish	*
<i>Labidesthes sicculus</i> - brook silversides	*
<i>Culaea inconstans</i> - fivespine stickleback	*
<i>Percopsis omiscomaycus</i> - trout perch	*
<i>Morone americana</i> - white perch	*
<i>Morone chrysops</i> - white bass	*
<i>Ambloplites rupestris</i> - rock bass	*
<i>Lepomis gibbosus</i> - pumpkinseed	*
<i>Lepomis macrochirus</i> - bluegill	*
<i>Micropterus dolomieu</i> - smallmouth bass	*
<i>Micropterus salmoides</i> - largemouth bass	*
<i>Poxomis nigromaculatus</i> - black crappie	*
<i>Poxomis annularis</i> - white crappie	
<i>Percina caprodes</i> - logperch	*
<i>Etheostoma nigrum</i> - johnny darter	*
<i>Etheostoma caeruleum</i> - rainbow darter	*
<i>Perca flavescens</i> - yellow perch	*
<i>Stizostedion vitreum vitreum</i> - walleye	
<i>Aplodinotus grunniens</i> - freshwater drum	*

The 1985 fish community in Hamilton Harbour and Cootes Paradise was dominated by warmwater planktivorous, herbivorous, and benthivorous species (Table 16). Alewife, White Perch, and Gizzard Shad represented 92 percent of the total catch in Cootes Paradise (52, 32, and 8 percent respectively) and 71 percent of the Hamilton Harbour catch (56, 15, and 0.1 percent, respectively). Differences in species composition reflected the presence of migrating species into Hamilton Harbour from Lake Ontario and reduced numbers of carp and Gizzard Shad in the Harbour. Large piscivores such as pike, garpike, Largemouth and Smallmouth bass, Channel Catfish, and bowfin were rare. The total number of fish captured in Hamilton Harbour and Cootes Paradise was similar although Hamilton Harbour received 30 percent more fishing effort.

Total fish biomass (kg of fish captured between April and September, 1985) in Cootes Paradise was 1.5 times greater than

the biomass in Hamilton Harbour (Table 17). Ninety-four percent of the fish biomass in Cootes Paradise was contributed by carp, Gizzard Shad, White Perch, alewife, and Brown Bullhead (Figure 11). These species contributed only 60 percent of the total biomass in Hamilton Harbour (Figure 11). Apart from reduced numbers of Gizzard Shad and carp in the Harbour, the most significant difference between the two sites was the contribution of other species to the total biomass. Thirty-two percent of the Hamilton Harbour biomass represented Lake Ontario species migrating into the Harbour. The largest contributors included White Suckers, Yellow Perch, Brown Trout, Spottail Shiners, and Rainbow Smelt (10, 9.2, 7.3, 3.6, and 2.4 percent of the total biomass respectively). The remaining 21 species contributed only 2.5 percent of the fish biomass in the Harbour.

The Hamilton Harbour and Cootes Paradise fishery consists of two distinct species groups. The first group, represented by crappies, sunfish, Gizzard Shad, and Brown Bullheads, remain in the Harbour and marsh throughout the year. They tend to congregate in Cootes Paradise in the spring and move into the western end of Hamilton Harbour in the fall.

The second major group, represented by smelt, White Sucker, Yellow Perch, Brown Trout, Spottail Shiners, herring, Lake Chubs, and Pacific Salmon, migrate into Hamilton Harbour from Lake Ontario to feed and/or spawn. Abundance is highest in the spring and fall (Table 18) although small numbers of migrating species were found in the summer at the eastern end of the Harbour close to the Burlington Canal.

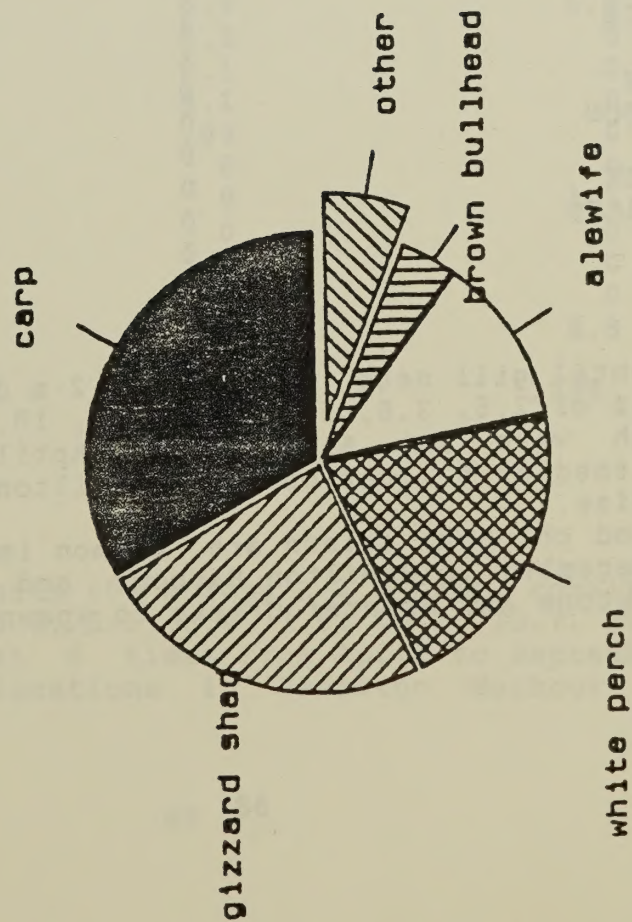
The Ontario Ministry of Natural Resources conducted an electrofishing survey in October, 1987 to determine the abundance and distribution of sportfish in Hamilton Harbour. Fishing was confined to the littoral zone (1.3 m deep). Fish density (no of fish per 300 m²) was determined from four 100 meter runs in each habitat type (Table 19 and Figure 9). Habitats were defined by the density of vegetation ranging from absent to dense.

Historically, the deep water habitat in Hamilton Harbour was used throughout the year by whitefish, lake herring, and lake trout. Kerr and Kerr (1860-1898) describe mass feeding migrations of lake herring and lake trout into the Harbour in June and July and spawning migrations of herring and whitefish in the fall. Acoustic surveys conducted in 1984 and 1985 indicate that fish were rarely found (densities never exceeded 0.1 fish/m³) at depths greater than 10 m during the summer months. Fish abundance in the deeper water increased in December, possibly a response to improved oxygen conditions.

Figure 11

Fish Biomass in Cootes Paradise and Hamilton Harbour (percent).

Cootes Paradise



Hamilton Harbour

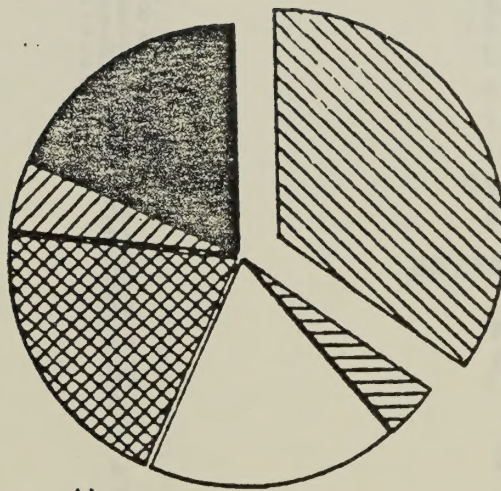


TABLE 16 Total gillnet^a catch in Hamilton Harbour
and Cootes Paradise from April to September, 1985

SPECIES	HAMILTON HARBOUR	COOTES PARADISE
ALEWIFE	9075	8612
WHITE PERCH	2449	5264
RAINBOW SMELT	1718	0
SPOTTAIL SHINER	841	97
YELLOW PERCH	746	124
BROWN BULLHEAD	458	725
WHITE SUCKER	308	66
GIZZARD SHAD	180	1309
CARP	99	370
BROWN TROUT	78	9
TROUT PERCH	45	17
PUMPKINSEED SUNFISH	29	46
WHITE BASS	14	3
FRESHWATER DRUM	11	12
CARP X GOLDFISH	10	9
ROCK BASS	6	1
LAKE TROUT	5	0
CHANNEL CATFISH	4	10
BLACK CRAPPIE	3	9
RAINBOW TROUT	2	5
GOLDFISH	2	17
NORTHERN PIKE	2	3
SMALLMOUTH BASS	2	0
LAKE CHUB	1	0
LAKE HERRING	1	0
WHITE CRAPPIE	1	0
BLUEGILL	1	0
LONGNOSE GAR	0	1
CHINOOK SALMON	0	0
COHO SALMON	0	0
COMMON SHINER	0	0
LARGEMOUTH BASS	0	0
BOWFIN	0	1
TOTAL	16091	16710

a Experimental gill nets (64 m long X 2 m deep) consisting of 8 m long panels of 2.5, 3.8, 5.1, 6.4, 7.6, 10.2, 12.7, and 15.2 cm stretch mesh were set 6 times from April to September, 1985. Nets were fished at 6 locations in Hamilton Harbour and 4 in Cootes Paradise.

b Coho and chinook salmon are common in Hamilton Harbour in October to December in Hamilton Harbour and Cootes Paradise and ascend Grindstone and Spencer Creeks to spawn.

TABLE 17: Biomass^a of fish captured in index gill nets^b in xHamilton Harbour and Cootes Paradise from April to September, 1985.

SPECIES	HAMILTON HARBOUR	COOTES PARADISE
WHITE PERCH	298.3	491.3
ALEWIFE	275.0	266.2
CARP	262.1	758.3
WHITE SUCKER	151.0	40.6
YELLOW PERCH	138.3	10.2
BROWN TROUT	108.6	16.8
GIZZARD SHAD	74.7	554.5
BROWN BULLHEAD	53.9	94.4
SPOTTAIL SHINER	42.1	1.4
RAINBOW SMELT	36.1	0
FRESHWATER DRUM	11.2	17.1
LAKE TROUT	10.6	0
CARP X GOLDFISH	10.2	11.5
NORTHERN PIKE	7.4	2.1
WHITE BASS	6.0	1.0
PUMPKINSEED SUNFISH	1.3	1.5
CHANNEL CATFISH	1.3	8.9
GOLDFISH	1.2	7.3
ROCK BASS	0.7	.2
BLACK CRAPPIE	0.6	1.7
TROUT PERCH	0.6	.2
SMALLMOUTH BASS	0.5	0
RAINBOW TROUT	0.4	6.9
LAKE CHUB	0.1	0
BLUEGILL	0.1	0
LAKE HERRING	0.1	0
WHITE CRAPPIE	.04	0
CHINOOK SALMON	0	0
BOWFIN	0	2.1
COMMON SHINER	0	0
COHO SALMON	0	0
LARGEMOUTH BASS	0	0
LONGNOSE GAR	0	0.8
TOTAL	1492.4	2295

a Kilograms of fish

b Experimental gill nets (64 m long X 2 m deep) consisting of 8 m long panels of 2.5, 3.8, 5.1, 6.4, 7.6, 10.2, 12.7, and 15.2 cm stretch mesh were set 6 times from April to September, 1985. Nets were fished at 6 locations in Hamilton Harbour and 4 in Cootes Paradise.

TABLE 18: Seasonal changes in the numbers of fish caught in index gillnets in Hamilton Harbour from September 1984 to September 1985^a and Cootes Paradise from April to September 1985.

HAMILTON HARBOUR

SPECIES	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WHITE PERCH	227	447	356	556	513	284	293	414	25
LEWIFE	72	1285	3445	832	499	441	101	19	5
ARP	3	7	20	23	27	19	40	58	9
WHITE SUCKER	67	73	33	33	20	15	29	28	37
YELLOW PERCH	151	255	88	80	48	39	93	38	12
BROWN BULLHEAD	151	255	88	80	48	69	158	80	30
BROWN TROUT	28	28	2	5	1	3	7	15	14

COOTES PARADISE

WHITE PERCH	1158	929	911	608	1038
LEWIFE	5	297	3273	3350	184
ARP	82	76	53	86	64
WHITE SUCKER	45	19	0	0	0
YELLOW PERCH	80	19	4	2	10
BROWN BULLHEAD	271	169	78	67	98
BROWN TROUT	3	1	2	0	2

Table 19
Electrofishing catches in Hamilton Harbour, October 1987

Species	No. of fish
Brown Bullhead	666
Pumpkinseed Sunfish	622
White Perch	337
Yellow Perch	75
Largemouth Bass	71
White Sucker	44
Alewife	37
Gizzard Shad	36
Carp	27
Rock Bass	15
Brown Trout	13
Chinook Salmon	10
Spottail Shiner	7
Emerald Shiner	7
Brook Silversides	5
Goldfish	5
Golden Shiner	4
Black Crappie	2
Bluntnose Minnow	2
Rainbow Trout	2
Smallmouth Bass	2
Channel Catfish	1
Redhorse sucker	1
Freshwater Drum	1
Total Number of Species	27
Total Number of Fish	2005
Number of Sport Fish	772

IV.2.3.7 Wildlife

Historically, the wetlands of Cootes Paradise and Hamilton Harbour provided a haven for thousands of migrant and resident waterbirds and a wide variety of marsh-dependent wildlife, including many commercially important species such as muskrat. However, documentation of this is largely restricted to passages in diaries, newspaper clippings and other writings, many unpublished. For example, one of the best available descriptions of pre-20th century Cootes Paradise is provided in the memoirs of former Dundas resident Charles Durand, who, in writing in 1893, recalled the area as it was during his childhood in 1818-19. "It was a paradise for game of all kinds. Immense flocks of ducks and wildfowl, and wild animals innumerable in old times were seen there. It was also the resort of wild fur animals, such as the otter, perhaps beaver, fisher, minks and especially muskrats; snakes were abundant there of all kinds".

Similarly, Thomas McIlwraith, a prominent Hamilton area ornithologist, described in 1861 flocks of waterfowl which inhabited Hamilton Harbour as "so great as frequently to darken the light of the sun by day, and make the night hideous with their discordant cries".

Though superficial, these accounts do give an indication that wildlife in the area was of very different character than it is today. To date, the most comprehensive attempt to define those changes, with particular reference to waterbirds, has been recently prepared by the Canadian Wildlife Service (CWS). Trends have emerged from the analysis which indicate that more species were common residents of the Harbour before 1948 (Dobos, R.Z. 1986).

Geographically the Cootes Paradise/Hamilton Harbour area lies within two broad and overlapping life zones: the Great Lakes-St. Lawrence and the Carolinian. Consequently, the flora and the fauna reflect elements of both of these major biomes.

The Stakeholders have identified the open water area of Hamilton Harbour and 5 shoreline areas within the basin as having significant wildlife associations and therefore requiring protection/enhancement in the RAP. The current status of the wildlife communities will be discussed in detail for each sub-area within the Harbour.

Sub-area Physical Descriptions

Cootes Paradise

Cootes Paradise is an 840 hectare wildlife sanctuary located at the extreme western end of Hamilton Harbour. The sanctuary is managed and almost wholly owned by the RBG. It has been classified by OMNR as a Class I wetland, an Area of Natural and Scientific Interest (ANSI) and is a Hamilton Region Conservation Authority ESA. The Canadian Wildlife Service includes Cootes

Paradise in an area ranked as the second most important waterfowl staging area in Lake Ontario and as the fourth most important on the lower Great Lakes (Dennis and Chandler, 1974). Cootes Paradise is important on a regional, provincial, national and international scale.

It is comprised of roughly 50% terrestrial upland habitat and 50% wetland habitat. The vegetation of the uplands is primarily climax forest with maple and oak predominating. Marsh vegetation comprises approximately 20% of the total wetland area, the remainder being open water. The shoreline is deeply indented, particularly on the south shore where numerous wooded ravines terminate in small coves or inlets. There are four major hydraulic inputs (Hopkins Creek, Chedoke Creek, Spencer Creek, and the town of Dundas STP).

Hendrie Valley/Carroll's Point

Hendrie Valley/Carroll's Point is an area of approximately 150 ha located in the lower reaches of the Grindstone Creek. The creek is a major watercourse whose headwaters originate above the escarpment in Flamborough and flow south from Waterdown. The Royal Botanical Gardens owns and manages the area, including the Carroll's Point water lot. This area has been designated an ESA in Halton Region. The vegetation is mixed deciduous forest on the slopes, with a small portion of open wet meadow and marshy bottomland where several small ponds vegetated with cattail and Manna Grass are located.

Pier 27 (Tollgate Ponds)

Pier 27 is an area of approximately 28 hectares in the southeast corner of Hamilton Harbour currently utilized for contaminated Harbour dredgate disposal by the Hamilton Harbour Commission. It is composed of two large ponds surrounded by rubble berms, and is gradually being filled with dredgate. The berm at the less disturbed north end is vegetated with shrub willows (Salix sp.) and young Eastern Cottonwood trees (Populus deltoides). This area has been designated an ESA in Hamilton-Wentworth Region.

Hydro Islands

The Hydro Islands are located in the northeast corner of Hamilton Harbour and consist of two stone islands once constructed to provide foundation for large hydro transmission towers. The towers have been removed from the islands. The islands provide breeding habitat for a large colony of Common Tern. The Hydro Islands have been designated an ESA in the Hamilton-Wentworth Region.

Windermere Basin

Windermere Basin is a 40 hectare, shallow (0.7-1.0 m) water basin, located at the southeast corner of the Harbour. It

receives hydraulic inputs from Red Hill Creek and the Hamilton STP.

Birds- Cootes Paradise

Though detailed information exists at RBG for terrestrial bird species, the present discussion is confined to waterbirds. It is sufficient to point out that breeding bird densities and species diversity are higher in the terrestrial habitats of the north shore when compared with those of the wetland habitats.

The marshes that border the west end of Cootes Paradise contain breeding rails, coots and Marsh Wrens in small numbers all of which have representatives that are regionally rare breeding species. West Pond is also frequented by several species of dabbling ducks, principally, American Black Duck (Anas rubripes), Common Merganser (Mergus merganser) and in the deeper canal, Hooded Merganser (Lophodytes cucullatus) during migration. There is also some evidence that Wood Ducks, (Aix sponsa) Blue-winged Teal (Anas discors) and Canada Goose (Branta canadensis) still breed in this area in small numbers and in 1977 the last known breeding attempt of the Black Tern (Chlidonias niger) reportedly occurred here. Herons and egrets regularly feed in West Pond. The remnant marsh which borders the south side of Spencer Creek willow line still provides breeding habitat for small numbers of bitterns, rails and Marsh Wren. A small pond formed by a break in marsh vegetation contains concentrations of waterfowl especially during spring migration and affords good feeding areas for herons particularly the Black-crowned Night Heron, (Nycticorax nycticorax).

On the north side of the Spencer Creek willow line, heavy autumn concentrations of dabbling ducks, principally, Green-winged Teal, (Anas crecca), Mallard (A. platyrhynchos), Gadwall (A. strepera) and Wood Duck occur. In addition Osprey, (Pandion haliaetus) herons and egrets are frequently seen feeding during migration.

At the end of the willow line, during low water years, an extensive mudflat is created. During 1984/85 a total of 27 species of shorebirds were recorded. This is considered one of the best areas in southern Ontario to observe shorebirds in the fall. In addition, it is an excellent feeding area for herons, egrets and all species of dabbling ducks, especially Green-winged Teal and Northern Pintail (A. acuta). The mudflats are also known for large concentrations of loafing terns and gulls. Seven species of the latter were recorded in 84/85.

The central open water area of Cootes Paradise is principally used by migratory ducks, especially diving ducks. This is the only area in Cootes Paradise that Common Loons, (Gavia immer), Red-necked Grebe (Podiceps grisegena) and Horned Grebes (P. auritus) are recorded. During the fall and early

winter, large numbers of Common Mergansers are observed feeding in this area until Cootes freezes. The old Desjardin Canal pilings provide an important preening location for Double Crested Cormorant (Phalacrocorax auritus), Common Terns (Sterna hirundo), Herring Gulls (Larus argentatus) and Great Black-backed Gulls (Larus marinus).

The aquatic areas at Princess Point/Chedoke Creek mouth are important waterbird concentration areas. In early spring, open water attracts early migrant waterfowl. In the fall, when water levels are lower, there are large numbers of dabbling ducks, especially Gadwall and American Black Duck. As well, gulls and a variable number of Canada Geese congregate during the fall.

There are a number of smaller remnant marshes which rim Cootes Paradise shoreline and they provide limited breeding habitat for a small number of regionally rare species such as the Sora Rail (Porzana carolina) and Least Bittern (Ixobrychus exilis).

Birds- Hendrie Valley/Carroll's Point

Waterbird usage of this area has three principal concentration points. A small patch of cattail near the canal which connects Cootes Paradise and the Harbour supported two species of breeding birds in 1984: the Mute Swan (Cygnus olor) and Common Moorhen (Gallinula chloropus). Both species are rare in the region. The open water in Carroll's Point bay is heavily utilized by nesting and migrating waterfowl. Diving ducks are very common here during spring and fall. During the winter, loafing gulls, particularly Greater Black-backed Gull, and Glaucous Gull (Larus hyperboreus) are associated with this area. At the mouth of Grindstone Creek, when low autumn water level expose mudflats, many species of shorebirds, such as the Common Snipe (Capella gallinago), congregate. This area is heavily utilized for feeding by Black-crowned Night Heron, Osprey and dabbling ducks particularly Gadwall.

Birds- Pier 27

The most outstanding feature of this area is the density and diversity of nesting colonial birds. The cottonwood trees provide nesting sites for a large colony of Black-crowned Night Herons. The Night Heron colony has been expanding steadily since 1975 when six nests were discovered (North, 1975). In 1987, the colony contained 212 active nests. The first Cormorant nest was found on the ground in 1984. Since 1985, they have increased dramatically in the cottonwood trees to 51 nests in 1987. The first nesting of the Snowy Egret (Egretta thula) in Canada occurred here in 1986 (Curry and Bryant, 1987).

The berms and filled cells of the containment area support a large Ring-billed Gull (Larus delawarensis) colony, which numbered over 21,000 nests in 1987. This is one of the largest

gull colonies on the lower Great Lakes. About 200 Herring Gull nests, 150 Common Tern nests and 134 Caspian Tern (Sterna caspia) nests are located around the gull colony. The nesting of Common Terns is regionally significant. The Caspian Tern is considered to be a rare species in Ontario and Canada (Cadman et al., 1987).

Other species which nest on the berms around the ponds are Canada Goose, Mallard, Gadwall, Spotted Sandpiper (Actitus macularia) and Killdeer (Charadrius vociferus). Species which have nested in the past include Green-winged Teal, Marsh Wren (Tetmatodytes palustris), Common Moorhen and American Coot (Fulica americana); all are regionally significant breeding species.

The ponds are used for staging by large numbers of migratory waterfowl in the autumn. Many species of shorebirds feed at the mudflats along the shores of the ponds during late summer and autumn, including several species rare to Ontario, such as the American Avocet (Recurvirostra americana) and Willets (Catoptrophorus semipalmatus) in 1987 (Jennings, 1987).

Birds- Hydro Islands

Members of the Ontario Bird Banding Association banded 552 nesting terns and counted over 200 nests from these two small islands in 1985. During the late summer and early fall Double-crested Cormorants use the islands for resting and preening.

Birds- Windermere Basin

Local naturalists know this area to be a regionally significant for waterfowl during the autumn and winter. Waterbird surveys of the Basin were conducted by CWS in the autumn of 1986. The average number of birds present per count was 1867, with the most numerous species being Scaup (Aythya sp.), American Black Duck, Mallard, and Bufflehead (Bucephala albeola) (Dobos and Weseloh, 1987). Average numbers of waterbirds during winter surveys increased to 4648 birds per count. Regionally significant species of waterfowl, which overwintered at the Basin, include Green-winged Teal, Northern Pintail, Northern Shoveler (Anas clypeata), Redhead (Aythya americana), Hooded Merganser and Ruddy Duck (Oxyura jamaicensis).

During low water periods in the late summer and autumn, migrating shorebirds including species rare in Ontario are attracted to the exposed sludge bank in large numbers. Recent rare sightings include a Piping Plover (Charadrius melodus) (Jennings, 1986b), an endangered species, and an American Oystercatcher (Haematopus palliatus) (Jennings, 1986a) (only the second record for Ontario).

Areas of marsh vegetation along the shore of the Basin which

are the only remnants of the once extensive marshes of Hamilton Harbour, provide nesting habitats for several bird species including Mallard, Gadwall, American Black Duck, Green-winged Teal, and Common Moorhen. At least 30 broods of waterfowl were observed there during the summer of 1987.

Birds- Hamilton Harbour proper

Hamilton Harbour has a diverse and abundant waterbird population associated with it. CWS waterbird surveys in the autumns of 1985 and 1986 recorded approximately 1200 birds per count composed of up to 43 species (Dobos and Weseloh, 1987). Birds were generally concentrated in groups at specific locations around the Harbour. The LaSalle Park Marina, the Hamilton marinas, and the northeast shoreline areas had the greatest numbers of birds per survey. The western end, Lax landfill, LaSalle Park Marina and the northeast shoreline areas had the greatest number of species of waterbirds. The steel factory shoreline, the centre of the Harbour, the Burlington residential shoreline, and the highway and railway shorelines had the fewest numbers and species.

One of the best spring and fall concentrations of waterfowl, namely scoters (*Melanitta* sp.), Tundra Swans (*Olor columbianus*) and mergansers is located directly below the Woodland Cemetery near the northwest shore.

Herptiles- Cootes Paradise

Significant concentrations of frogs and turtle species still occur in many localized wetland habitats.

Frogs are especially abundant wherever vegetation remains flooded throughout spring and fall. The Northern Leopard Frog (*Rana pipiens*) and American Toad (*Bufo americanus*) are the most common species and are well distributed in all marshy areas, but especially abundant in the old Spencer Creek bed. The Green Frog (*Rana clamitans melanota*) also occurs here. The Western Chorus frog (*Pseudacris triseriata*) is uncommon and found in small patches of marsh vegetation.

Turtle populations in Cootes Paradise are high in species diversity and abundance. The preferred areas of concentration are those which provide good basking sites and readily available food such as in the old Spencer Creek bed, Westdale Inlet and backwater ponds at the extreme western end. One of the latter ponds rivals other sites in North America as the highest estimated density of the Midland Painted Turtle (*Chrysemys picta marginata*). Similarly, Snapping Turtles (*Chelydra serpentina*) densities in the western end of Cootes are considered very high, when compared to other sites, especially during breeding season in early June, when many females seek a suitable substrate for egg laying. The shoreline in this area provides good opportunities for this activity, and it is likely that the

largest segment of the population in the western end resides there. Small populations of turtles such as Blanding's (Emydoidea blandingi), found only in old Spencer Creek bed, have quite restricted distribution, while a regionally uncommon species of the Map Turtle (Graptemys geographica) occurs in fair (20-30) numbers in Westdale Inlet.

Herptiles- Hendrie Valley/Carroll's Point

Reptile and amphibian populations of the area are characterized by species which are local or regionally significant. For example, both Bullfrog (Rana catesbeiana) and Pickerel Frog (R. palustris) still occur in backwater ponds bordering the lower Grindstone Creek, albeit in restricted numbers. In addition, there is a large population of Map turtles present and an Eastern Spiny Soft Shell Turtle (Trionyx spiniferus spiniferus) was sighted on two occasions in 1984 and one specimen was caught in 1982. This latter species is considered extremely rare and, at one time, was thought to have been extirpated from Lake Ontario (Campbell, C. 1977 cited in Obbard and Down, 1984).

Herptiles and Mammals- Windermere Basin

Other wildlife known to occur in the Basin, include Muskrat, Eastern Cottontail (Sylvilagus floridanus), Ring-necked Pheasant (Phasianus colchicus), Midland Painted Turtle and Common Snapping Turtle.

Mammals - Cootes Paradise

Sixteen species of large mammals occur here. They range from a small mobile herd of less than 20 White-tailed Deer (Odocoileus virginianus), which roam freely in distinct travel corridors between the north shore of Cootes Paradise and the Niagara Escarpment, to a large and well distributed population of Raccoon (Procyon lotor), which intermixes with high density housing on the south shore. The principal semi-aquatic mammals are Mink (Mustela vison), Muskrat (Ondatra zibethica) and Beaver (Castor canadensis). One individual of the latter species was recorded living in a bank den in the lower reaches of Spencer Creek in 1984. The muskrat population, estimated at less than 100 individuals, is confined to small localized pockets of emergent vegetation, primarily cattail (Typha sp.) and Manna Grass (Glyceria maxima), which rim the Cootes Paradise basin. Muskrats are concentrated in west pond and in bank dens along Spencer Creek. Mink are present in unconfirmed numbers and are commonly associated with the streams of the north shore.

Mammals- Hendrie Valley/Carroll's Point

Muskrats are found along the Grindstone Creek wherever suitable habitats exists. Bank dens and lodges in the ponds are currently utilized. In 1984, 30 individuals were counted and in 1985, 17 individuals were live-trapped along the creek. Mink were confirmed in 1984 but not quantified.

IV.2.4 Impact of Hamilton Harbour on Western Lake Ontario

The net drift measured over periods greater than 1 or 2 weeks is to the south-southeast due to large counter-clockwise circulation patterns in Lake Ontario. Water currents just offshore in western Lake Ontario are highly variable and relatively weak. Current speeds vary from 0-12.8 cm/sec with currents less than 5 cm/sec observed for 58% of the time. Speeds are faster in winter. Periods of "stagnation" ranged from 0.5 to 12 days with most being less than 5 days. Periods of stagnation in other coastal areas of the Great Lakes are usually less than a day. This difference is due to the fact that Hamilton Harbour is located in the extreme, and narrow elliptical western end of Lake Ontario. Since circulation is generally counter-clockwise, the flow approaching the western end of the lake must slow down before turning south and then east along the southern shore.

The extent of travel of water from Hamilton Harbour through the Burlington Ship Canal, has been estimated to be 0.5-1.5 km. due to momentum of water leaving the Canal. The concentrations of pollutants are diluted 9 times on the average at a distance of 1250 meters from the Canal. The Burlington and Hamilton water intakes are about 5 km from the Canal.

The annual average suspended sediment loading to Lake Ontario from Hamilton Harbour was estimated to be 9,800 kg/day based on 1983/84 studies, compared with 15,900 kg/day in 1979 (Poulton et al., 1986). This apparent reduction is qualitative only, and requires verification. The suspended solids load could be quite variable from year to year.

Concentrations of all metals in sediments in the nearshore zone of western Lake Ontario increased with depth and the higher values were generally found at stations where the mean sediment particle size was less than about 50 μm . Comparison of the average concentrations of metals at nearshore stations with those measured in the uppermost 1 cm of cores from a depth of 100 m in the Niagara Basin shows that amounts in the nearshore zone are 3-20x less. These distributions appear to suggest that metallic discharges from Hamilton Harbour may not have a significant impact of the sediment quality in the area immediately adjacent to the Burlington Ship Canal. This is consistent with studies which indicate that most trace metals are exported from the Harbour in association with fine particles which would have a short residence time in the nearshore zone (Poulton et al., 1986).

Results of sequential extraction analysis on sediments collected in 1982/83 (to identify the geochemical forms of metals) suggest that metals are less bioavailable outside the Harbour than inside (Poulton et al., 1986). However, a 1983 study comparing sediments from outside the Harbour to those from

Windermere Basin showed this difference to be relatively slight (Persaud et al., 1987).

PAH analysis on sediment samples from outside the Harbour showed that the PAH concentrations depended upon the distribution of fine-grained sediment particles in a fashion similar to total metals. Based on the pattern of PAH concentrations in the sediments, there appears to be a second source of PAHs to the east of the Burlington water intake.

Analysis of material collected in sediment traps within the Harbour during 1987, and future measurement of the quality and quantity of suspended material entering and leaving the Harbour will clarify the effects of the Harbour on Lake Ontario.

The Hamilton and Burlington water intakes were sampled weekly from May 20 to September 1, 1982 and the water chemistry was compared to offshore and Harbour plume water chemistry. Burlington water intakes had consistently higher copper concentrations than either the offshore or Harbour plume water suggesting a local source of copper. Of the 21-23 survey dates, only 4-6 days had elevated concentrations of ammonia, of which only 1 day appears to be caused by Hamilton Harbour. The other days can be explained by local loadings, storm events and resuspension phenomena. The occasional elevations of trace metal concentrations also appear to be from sources other than Hamilton Harbour. Therefore of the 21-23 days studied, only 1 day at the Hamilton water intake was apparently influenced by the plume from Hamilton Harbour. The dilution of the plume by a factor of at least 9 with Lake Ontario water and the fact that Hamilton Harbour water itself has not exceeded the Provincial Water Quality Objectives for the last two years would suggest that the possible impact of the Harbour plume on the two water intakes is not a concern at this time.

The Provincial Drinking Water Quality Program has monitored both intakes for 3-4 years and there is very little evidence of impact on water quality by Hamilton Harbour.

Bacteria sampling in the Confederation Beach area confirms the drinking water intake observations. Elevated bacteria counts are a result of local sources and not a result of the Hamilton Harbour plume. Runoff from creeks during and after rainfall events seems to be the most probable source of bacterial contamination. Since the fecal coliform counts in Hamilton Harbour have been below the guideline, the plume is probably not responsible for beach closures adjacent to the Canal in Lake Ontario.

Priority pollutant loading to Hamilton Harbour is approximately 366 kg/day based on 1984-85 data. The net loading to Lake Ontario from the Harbour has been estimated to be 139

kg/day. Of the 139 kg/day loading of priority pollutants to the Lake, 119 kg/day (85%) are heavy metals of which zinc is 66 kg/day (55% of the metals and 47% of the total). The loadings to Lake Ontario from Hamilton Harbour, and Canadian and US Niagara River loadings are compared in Table 20.

Table 20: Priority Pollutant Loadings to Lake Ontario (kg/day)

	Hamilton Harbour	Canadian Niagara	US Niagara
Heavy metals	119	66.6	990
Cyanide	<15.6	1.2	43
Phenolics	<3.3	nd	158
Volatile organics	nd	1.3	133
Acid Extractable	nd	nd	46
Base-Neutral Ext. (other than PAHs)	nd	0.3	21
PAHs	1.4	nd	17
Organochlorine pesticides	0.034	nd	1.1
PCBs	0.021	nd	0.1
Total	139.4	69.4	1409

IV.3 SPECIFIC CONCERNS

IV.3.1 Impaired Uses

The Water Quality Board of the International Joint Commission assessed Hamilton Harbour in their 1985 report. A summary of their assessment, based on submissions by the Ontario Ministry of Environment, is included here.

IJC Water Quality Board Assessment HAMILTON Harbour (Ontario) NATURE OF PROBLEM June 1985

Types of Problems

Conventional Pollutants
Heavy Metals
Toxic Organics in Fish
Contaminated Sediments
Eutrophication
Fish Consumption Advisories
Aesthetics

Sources

Municipal Point Sources
Industrial Point Sources
Urban Nonpoint
Combined Sewer Overflows
In-Place Pollutants

Municipal and industrial discharges, urban drainage, sediments, and algal decay increase oxygen demand. This oxygen demand depresses hypolimnetic dissolved oxygen levels, especially in the summer. This, in turn, limits the suitability of the deeper part of the Harbour as a fish habitat.

Aesthetic quality is diminished by poor water clarity and colour, as a result of high levels of suspended solids, chlorophyll, and dissolved organics, thereby deterring broader recreational use of the Harbour.

Significant levels of nutrients, several heavy metals, and PCBs have been detected in the surface sediments from several portions of Hamilton Harbour. The problem is severe in Windermere Basin. Dredged material is disposed in confined areas.

Objectives are exceeded for total dissolved solids, zinc, ammonia, and phosphorus. Iron, cyanide, and phenolics also exceed the objectives on occasion, especially adjacent to the steel mills on the south shore.

Levels of trace organics (PCB, PAH), phenols in fish are under investigation.

This assessment has, as its base, assumptions regarding the impairment of uses. The hypolimnetic dissolved oxygen problem in the Harbour limits fish habitat. The Water Quality Objectives are based on levels of pollutants which will protect aquatic biota. The aesthetic quality is based on an appreciation of the water body for recreational activities other than swimming. If swimming is also to be considered as a use, then bacterial levels need to be addressed. However, since swimming is currently illegal in the Harbour, the MOE has not included bacterial quality in the assessment.

IV.3.2 Water

IV.3.2.1 Conventional Pollutants

From 1962 to 1985, the industrial loadings of conventional pollutants to the Harbour have been reduced 60-95%. From 1977 to 1983, the concentration of BOD in the water column decreased from 3.39 to 3.09 mg/l. The seasonal average concentrations of suspended solids in the Harbour are low and from 1976 to 1980 the concentrations decreased from 5.76 to 4.68 mg/l. Cyanide concentrations in open water were consistently below the detection limit of 5 µg/l. The Provincial Water Quality Objective is 5 µg/l. Phenol concentrations in open water are below the objective of 1 µg/l. However, phenol concentrations were at one time 10-50 µg/l.

Ammonia concentrations are currently above the recommended concentrations which effect fish. Seasonal pH and temperature trends are used to calculate the total ammonia concentration below which ammonia no longer has an effect.

Hypolimnetic dissolved oxygen concentrations are below the Objective of 4-5 mg/l for warm water fish. The IJC has stated that the dissolved oxygen in hypolimnetic waters should be not less than the concentration necessary for the support of fish life.

IV.3.2.2 Heavy Metals

Loading reductions for copper, zinc, chromium, cadmium and lead have occurred since 1977. Exceedences of the Provincial Water Quality Objectives have rarely occurred since 1984.

IV.3.2.3 Organic Contaminants

PCBs and γ-BHC exceed provincial water quality objectives 14% of the time. Significant reductions in PAH loadings have occurred.

IV.3.2.4 Eutrophication

Total phosphorus concentrations over the last four years have averaged 57 µg/l in the centre of the Harbour. Soluble reactive phosphorus concentrations have averaged 17 µg/l. Total phosphorus is now believed to be low enough to influence algal productivity although physical processes such as mixing depth and photic depth are considered the most controlling factor. Chlorophyll a concentrations in the surface waters of the central Harbour have averaged 19 µg/l over the last four years.

Secchi disc transparencies during 1987 averaged 1.4 m in the centre of the Harbour. Shoreline Secchi disc transparencies averaged 0.95 m but only the first 100 meters from shore had these reduced transparencies. Any location with water depths greater than 2 meters had a water clarity similar to offshore water clarity.

IV.3.3 Sediments

Elevated concentrations of contaminants in lake sediments are of concern because of potential toxicity or food web related impacts on aquatic biota, particularly benthic invertebrates. Effects on benthic organisms may be acute or chronic and in either case may lead to an adverse impact on community structure. This may disrupt the species diversity and numbers of predator organisms and ultimately lead to the loss of desirable species at higher trophic levels (e.g. sport fish).

The profundal benthic community of Hamilton Harbour reflects the impact of low dissolved oxygen during the summer months. Low hypolimnetic oxygen concentrations from mid June to mid September limits the deep water benthos to species that can withstand low dissolved oxygen for prolonged periods. Although sediments in the deep water basin are contaminated with organic and inorganic pollutants, the toxicity of these chemicals on benthic invertebrates are masked by the adverse effects of low dissolved oxygen. Attempts to correlate the abundance and composition of the benthic community with contaminant concentrations failed because of auto-correlations between contaminant concentrations, organic composition of the sediment (grain size), depth, and dissolved oxygen (Portt et al. 1988)

Sediment extracts from 7 of 62 locations in Hamilton Harbour killed 70% or more of the zooplankter, Daphnia magna, within 48 hours (Figure 12). The more toxic sediments were adjacent to the Steel Mills. The sediments from the northern and western portions of the Harbour were either not toxic or killed less than 30% of the Daphnia. Whole sediments from near the steel mills greatly depressed the oxygen consumption of the bacteria Photobacterium, whereas other sediments were much less toxic (Figure 13). The oxygen demand of the sediments was significantly correlated with the acute toxicity of the sediments to Daphnia. The acute toxicity of the sediments to Daphnia was reduced by either bubbling the sediments with oxygen for 2 days or by addition of 10-200 mg/l of lime. The concentrations of copper, iron, and zinc in some sediment extracts exceeded levels known to be toxic to Daphnia; however, a simple relationship between sediment toxicity and metal concentration could not be found.

Elevated concentrations of zinc, lead, copper, and iron in the deep water sediments suggest that these sediments may be toxic to burrowing organisms such as Pontoporeia and Chironomus. Dermott (1988) conducted bioassays to determine the acute toxicity of various Hamilton Harbour sediments to the amphipod, Pontoporeia hoyi and to the chironomid, Chironomus semireductus. Both species are dominant benthic invertebrates in portions of Lake Ontario, with Chironomus being common in the shallow bays of the lake. Pontoporeia, an important food organism for whitefish, was abundant in Hamilton Harbour in the late 1800s.

Figure 12

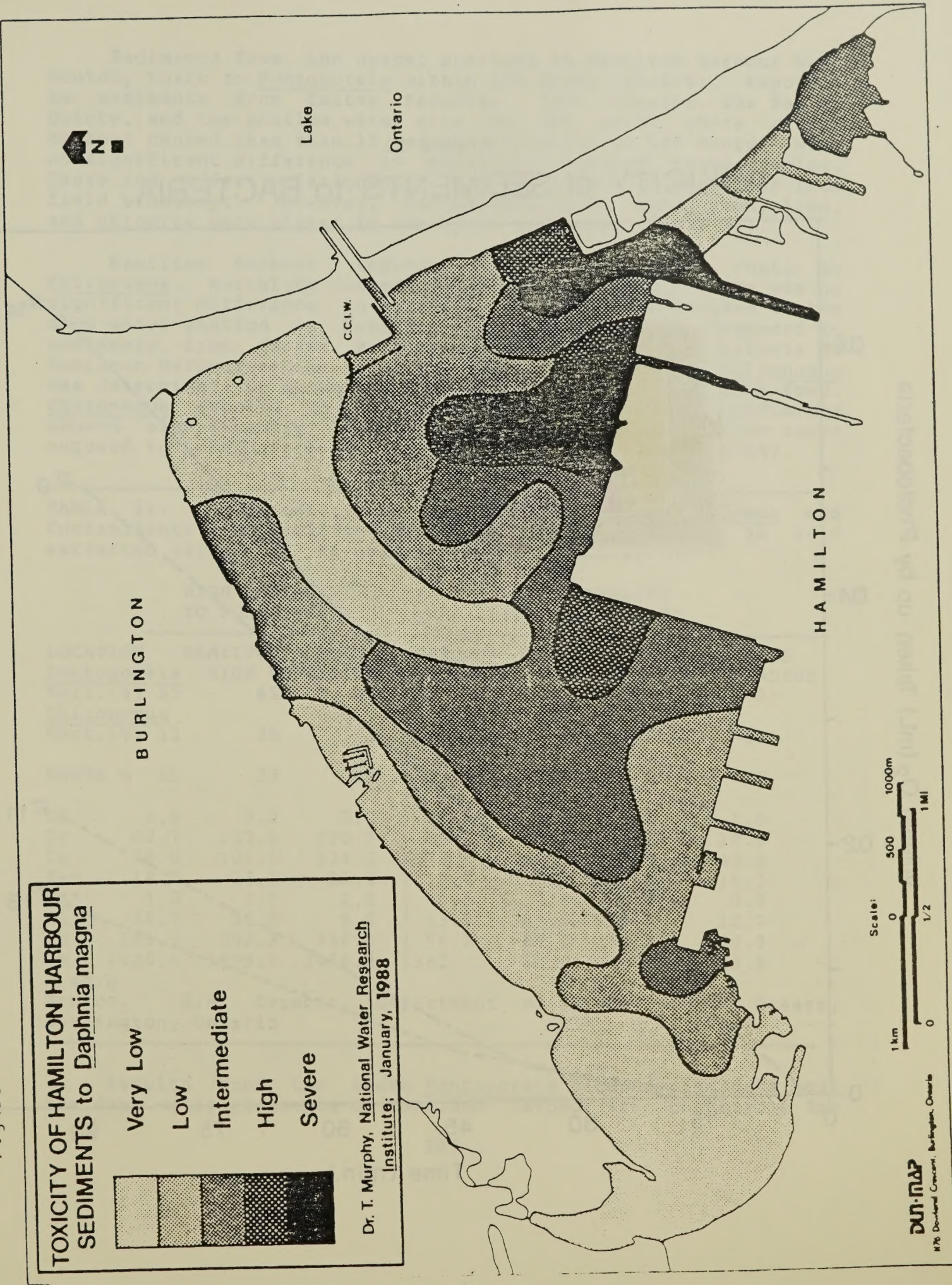
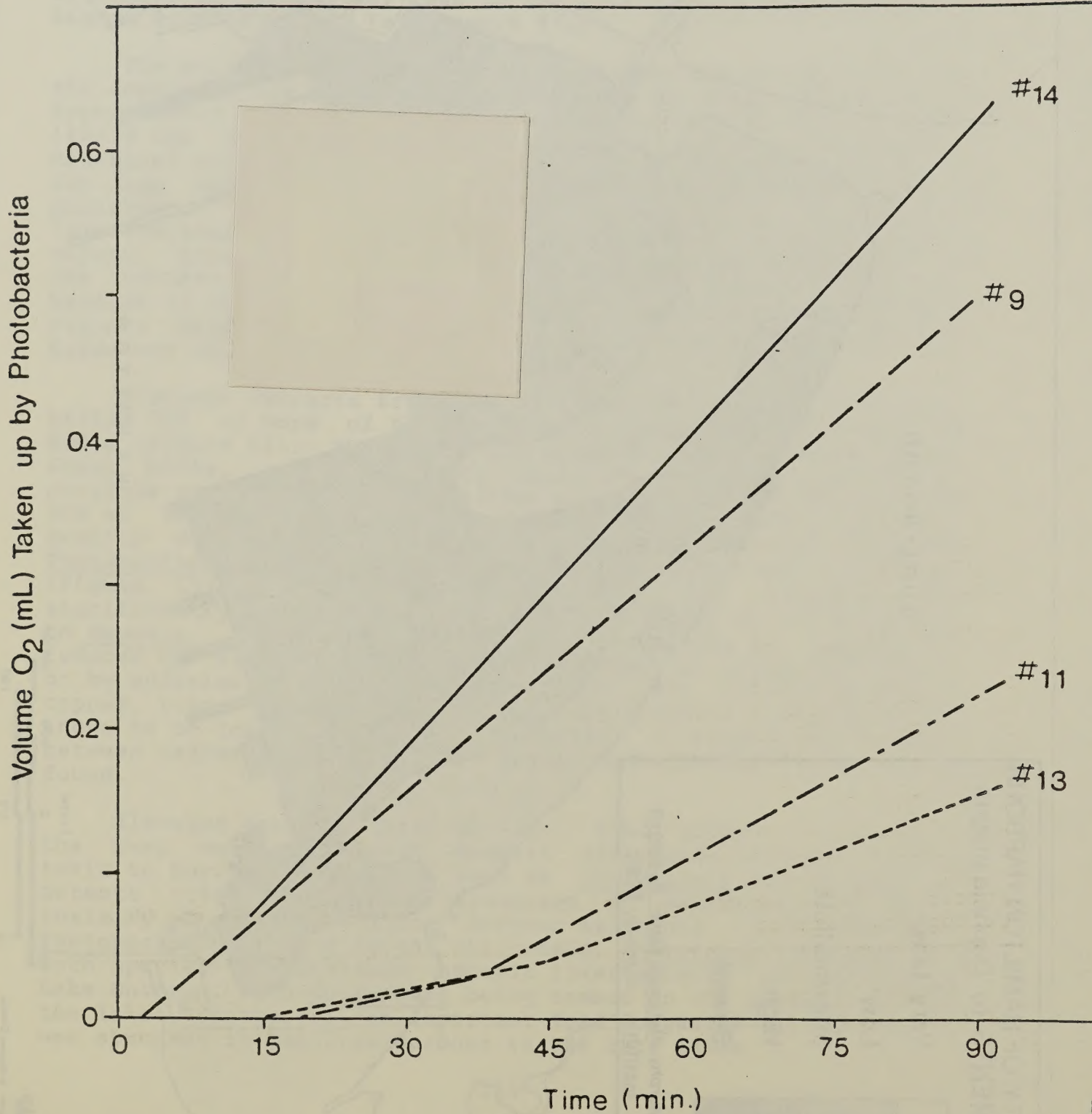


Figure 13

TOXICITY of SEDIMENTS to BACTERIA



Sediments from the deeper stations in Hamilton Harbour were acutely toxic to Pontoporeia within 168 hours (65-85%). Exposure to sediments from Cootes Paradise, Lake Ontario, the Bay of Quinte, and the shallow water site on the north shore of the Harbour caused less than 15 percent mortality in 168 hours, with no significant difference in mortality between these samples. Cause and effect relationships are difficult to establish from field bioassays. However, concentrations of zinc, lead, iron, and chromium were higher in the toxic sediments (Table 21).

Hamilton Harbour sediments were not acutely toxic to Chironomus. Mortality ranged from 5 to 32 percent. There was no significant difference in mortality of Chironomus exposed to the deep water station in Hamilton Harbour and those exposed to sediments from Cootes Paradise. The sublethal effects of Hamilton Harbour sediments on the feeding activity of Chironomus was determined by measuring the percent of gut filled with food. Chironomus exposed to Hamilton Harbour and Cootes sediments showed significantly lower feeding activity (24%) from those exposed to Lake Ontario or the Bay of Quinte sediments (72%).

TABLE 21: Mortality of Pontoporeia and Chironomus and Contaminants in Hamilton Harbour sediments, metals as acid extracted values, mg/ kg unless otherwise stated.

LOCATION	HIGH MORTALITY TO PONTOPOREIA			LOW MORTALITY TO PONTOPOREIA			
	HAMILTON HARBOUR	HIGH MORTALITY		HARBOUR	LAKE	BAY OF	COOTES
<u>Pontoporeia</u>				LOW MORT.	ONT	QUINTE	PARADISE
Mort.(%) 65	65	85		5	10	15	8
<u>Chironomus</u>							
Mort.(%) 12	25	15		13	8	7	23
DEPTH m 11	23	19		5	125	5	2
Cd	3.9	5.2	0.2	2.9	2.0	1.4	1.0
Cr	62.7	122.6	150.7	30.7	17.6	10.5	10.9
Cu	76.0	101.0	274.6	73.8	68.7	26.7	43.3
Fe*	14.2	23.2	25.4	10.7	10.4	10.5	10.3
Mn*	1.5	2.0	2.0	0.6	1.6	0.6	0.7
Ni	28.7	35.0	0.6	13.9	41.0	16.0	12.7
Pb	181.7	292.3	336.0	56.2	87.0	54.2	69.3
Zn	1425.4	1999.7	2468.3	382	12.0	128.7	253.5

* mg/g

Source: R.M. Dermott, Department of Fisheries and Oceans, Burlington, Ontario

Results from the acute Pontoporeia bioassay indicate that the deep water sediments of Hamilton Harbour are unsuitable for

colonization by Pontoporeia. Cause and effect relationships are unknown and research is needed to identify the toxic agent(s) and develop remedial actions. Results from the Chironomus bioassay are more difficult to interpret. Low acute toxicity in all Harbour sediments suggests that Chironomus would be successful throughout the Harbour if dissolved oxygen was not limiting. However, reduced feeding activity in the short term assay (192 hours) has implications for growth and long term survival and it is not clear if Chironomus could successfully colonize the deep water sediments.

Biomagnification of contaminants by benthic organisms may also be of concern due to the potential for transmission to predator species and subsequent accumulation through the food web.

Benthic macroinvertebrates (chiefly tubificid oligochaetes) in Windermere Basin and near the Ship Canal in Lake Ontario exhibit tissue concentrations of metals (Cu, Fe, Hg, Zn) and certain organochlorine compounds (PCBs, HCB, DDE, chlordane, heptachlor, aldrin, α -BHC) (Persaud et al., 1987) which suggests that a transfer from sediments into the aquatic food web is taking place.

Interpreting tissue concentrations in benthic invertebrates and fish is difficult due to our lack of ability to separate the effects of present contaminant loadings to the water from the effects of high contaminant concentrations in the sediment as a result of past loadings. In other words, when are abatement actions at the sources no longer effective at resolving the problem and remedial measures to deal with the historical loadings become necessary.

Mobility of contaminants in the sediment due to either physical resuspension of sediment particles, bioturbation, geochemical reactions or biomagnification is poorly understood in Hamilton Harbour. Only manganese and occasionally iron release from the Harbour sediments has been documented. Biomagnification of contaminants into benthic invertebrates has been observed but the significance to a warmwater fishery has not yet been estimated.

Sediment trap measurements of suspended sediment fluxes throughout the Harbour in 1987 suggest that resuspension of surficial sediments (and hence recycling of associated contaminants into the water column) appears to be occurring in deep areas of the Harbour as well as those boundary areas most obviously affected by ship traffic and wave action (Charlton pers. comm.). Analysis of such physical properties as particle size and organic content will assist in the interpretation of the processes responsible for resuspension.

IV.3.4 Biota

IV.3.4.1 Populations

Marsh Vegetation in Cootes Paradise

The marsh flora of Cootes Paradise bears little resemblance to that which pre-20th century writings have described. The memoirs of Charles Durand (1893), a former Dundas resident, provide some insight into that period's natural history. Durand implies that the marsh in early 19th century, when he was a boy, was virtually filled throughout its length with emergent aquatic plants. Photographs currently on file at RBG confirm that as late as 1928 there were, in fact, emergent aquatics growing as far east as the mouth of the Desjardins Canal at the High Level Bridge.

Percentages of emergent plant cover which have occurred in Cootes Paradise from 1934 are shown in Table 22.

Table 22: Extent of Emergent Vegetation in Cootes Paradise

<u>Year</u>	<u>% of total area</u>
1934	100
1946	41.6
1950	25
1953	12.6
1954	20
1959	40
1962	32
1971	27.9
1972	27
1974	9.3
1980	15
1985	16.9

Source: V. Cairns, Department of Fisheries and Ocean and RBG

Mr. George North (b.1910-d.1983), an amateur naturalist and keen long-time observer of Cootes Paradise, described the marsh flora as it was during the 1920s and early 1930s (pers. comm. to J. Lord of RBG). According to North, the most abundant emergent plant was cattail (Typha sp.) and was associated with many other common wetland species such as burreed (Sparganium ssp) water lily (Nymphaea spp.) and water smartweed (Polygonum punctatum). North noted that manna grass (Glyceria maxima), which is currently the dominant emergent of the marsh, became evident much later. In addition to these emergent species, there were vast amounts of submergent aquatics. Wragg, (1954), although he did not cite specific references, also described the marsh circa 1920 in the following way .. "Judging from reports of its condition, 30 years ago it must have been a remarkable place. In addition to the abundant growth of aquatic plants found there today, wild celery (Vallisneria americana) was common and wild rice (Zizania aquatica) so abundant that, in rowing through the marsh, one's

boat would be covered with rice. Water was so clean and food so plentiful that ducks remained in thousands until ice formed. "Wragg noted that a decline in waterfowl usage, concurrent with a decline in wild rice and wild celery stands, occurred in the 30 years which ensued.

Based on interpretation of historical writings and other sources, permanent reduction of wetland vegetation appears to have begun sometime around the turn of the century and has accelerated rapidly since the 1940s. Though documentation is fragmentary, several factors appear to have contributed to this decline. High water events have been shown to be correlated with a decrease in abundance and distribution of emergent plant communities in Cootes Paradise (Dept. of Fisheries and Oceans, unpublished data, 1986). However, based on historical descriptions, permanent reductions in marsh vegetation prior to the turn of the century were not experienced. Lake Ontario historical water level records from 1840 to present have undergone wide fluctuations including extended periods of high water during the 1800s, without permanent damage to the macrophyte communities. (S. Painter, unpublished data, 1986). Apparently the emergent vegetation recovered when water levels returned to normal. It would then appear that factors other than water level are involved in the marsh decline.

Turbidity caused by algal blooms (in response to high nutrient loading) can cause inhibition of submergent plant growth, ultimately resulting in elimination of plant communities. The Dundas STP has been implicated as the primary source of excessive nutrient loadings to Cootes Paradise since its construction in 1919. It is postulated that the levels of nutrients discharged into the marsh from the STP and other sources, in addition to promoting algal blooms, may have led to the weakening and breakage of stems of some species of emergent macrophytes. This may have occurred in response to the high concentration of nutrients, particularly nitrogen, to which Cootes Paradise has been subjected. This mechanism can cause widespread loss of macrophyte stands, only where the vegetation is growing on a floating root and rhizome mat. (Boar and Crook, 1985). The extent of the marsh that was floating and therefore possibly affected by high nitrogen loading is unknown.

Turbidity derived from suspended sediments (erosion from urban storm water drainage) reduces light penetration. Silt may also coat leaves, further inhibiting photosynthesis, and may physically damage stems and leaves. High silt loadings can also change substrate texture rendering it unsuitable for some plant species to colonize. Siltation in Cootes Paradise has changed bottom contours dramatically, resulting in a shallower basin particularly in the eastern portion (S. Painter, unpublished data 1986). This shallowness has fostered wind-generated resuspension

of bottom sediments and therefore has compounded the light penetration problems created by phytoplankton blooms.

A major role in the decline of the Cootes Paradise macrophyte communities must also be attributed to the spawning and feeding activities of carp (Cyprinus carpio) in the marsh. Carp were implicated by Wragg (1954) as responsible, in part, for the eradication of wild rice and wild celery from Cootes Paradise 30 years before he undertook his studies. Though he did not cite references Wragg suggested that the apparent failure to re-establish these two plants, circa 1937, was again due to the destructiveness of carp. An ambitious programme of carp control was conducted by the Royal Botanical Gardens in 1952 and again in 1954-56. The latter effort removed 130,000 adult carp and resulted in dramatic improvement in the distribution and abundance of aquatic vegetation in the marsh (Lamoureux, 1961). However, the programme was discontinued and has not been attempted since that time.

There are a number of other minor factors which may have contributed to the decline of macrophyte communities in Cootes Paradise. For example, damage to replanted wild rice stands from 1951-56 was caused by larvae of an unidentified species of moth (Lamoureux, 1957). In addition, grazing by muskrats may have had some local effects, but whether permanent damage occurred is unknown.

It would appear that the major factors currently limiting recovery of the macrophyte communities in Cootes Paradise are turbidity, high water and carp. If marsh restoration is to be achieved, practical methods of controlling these factors must be sought.

Hamilton Harbour Aquatic Vegetation

The composition and abundance of warmwater fisheries in Hamilton Harbour is influenced by the type, density, and distribution of submerged and emergent aquatic plants. Apart from an obvious role in sediment stabilization, aquatic vegetation provides essential fish habitat. The extent of submerged macrophyte cover influences phytoplankton and zooplankton populations, increases epiphytes, and littoral invertebrates and provides spawning, nursery, and adult habitats for Largemouth Bass, pike, bowfin, sunfish, Longnose Gar, and crappies. Fisheries production in the littoral zone appears to be optimum at intermediate plant densities. Sparsely vegetated areas offer little protection from predators while extremely dense vegetation impedes larger predators and reduces feeding success. Plant abundance is influenced by light, water levels, nutrients, substrate characteristics, ice scour, and lake morphometry (Duarte et al., 1986).

Emergent vegetation provides spawning habitat for Largemouth Bass and Northern Pike. Pike prefer flooded sedges (Carex sp.), grasses (Spartina, Phalaris) and water plantain (Alisma). They will also spawn on flooded mats of broken cattails (Typha).

There are no data quantifying the extent of emergent marsh vegetation in Hamilton Harbour prior to 1900. Kerr and Kerr (1864 - 1898) reported that marshes extended along the entire south shore of the Harbour, in the north east corner (Brant's Pond), and in the mouth and lower reaches of Grindstone Creek. The entire 49.6 km south shore (from Desjardins Canal to the Burlington Canal) was restructured between 1800 and 1985 (Fig. 1) resulting in a loss of 69 percent of the original vegetated shoreline (Table 23). Whillans (1979) concluded that the loss of the south shore marsh was a major factor contributing to the decline of the warmwater fishery.

TABLE 23: Changes in the littoral shoreline in Hamilton Harbour from 1800 to 1985.

YEAR	LITTORAL PERIMETER (km) ^a		% REDUCTION
	1800	1985	
NORTH SHORE ^b	15.7	13.3	15.2
SOUTH SHORE ^c	49.6	7.2 ^d	85.5
TOTAL	65.3	20.5	68.6

a The shoreline perimeter fronting depths from 0 to 2 m

b From the north shore of the Burlington Canal to the north shore of Desjardins Canal

c From the south shore of Desjardins Canal to the south shore of the Burlington Canal

d Excluding Windermere basin

Source: 1800 map of Hamilton Harbour prepared by T. Watson for the Head of The Lake Society from the original survey data of Augustus Jones 1790-1809. The 1985 data was taken from the 1985 chart of Hamilton Harbour.

The emergent marsh in Grindstone creek declined from 37.8 ha in 1934 to 5.1 ha in 1985 (Table 24). Most of the loss (23 ha) occurred in the area of the Valley Inn Road. Possible factors responsible for marsh loss include ice scour, damage by carp, siltation, reduced light penetration, and increased water levels. Recent analysis of marsh losses since 1934 showed a good correlation with elevated water levels (V. Cairns, pers. comm.).

The Grindstone Creek marsh is the last remaining stand of emergent vegetation in Hamilton Harbour and the only site

suitable for pike reproduction. Eighteen adult pike were observed in the vicinity of the boardwalk marsh in 1985. Only 1 pair were spawning. There was no evidence of pike spawning in Cootes Paradise in 1985 or 1987.

TABLE 24: Changes in emergent vegetation in the Grindstone Creek marsh from 1934 - 1985

YEAR	AREA (ha)			
	Valley Inn	Sunfish Pond	Lower Marsh	Boardwalk Marsh
1934	23.0	2.6	6.9	5.3
1939	3.5	2.6	7.9	5.7
1950	1.1	0.1	2.4	3.5
1954	3.0	0.5	1.2	4.2
1959	1.1	2.3	4.9	4.2
1961	0.7	0.9	3.5	5.0
1969	0.6	0.5	1.9	3.8
1972	10.2	0.6	3.4	3.6
1974	0	0.2	0	1.4
1980	0.4	0.4	1.4	3.5
1985	0.4	0.3	0.7	3.7

There is insufficient spawning habitat (emergent marsh) in Hamilton Harbour to support a viable pike fishery (20-25 kg/ha). The ratio of spawning habitat to adult habitat is 0.06 in Hamilton Harbour (using 1987 data of 5 ha of suitable spawning habitat in Grindstone Creek and 90 ha of vegetated adult habitat in the Harbour). This is considerably less than the 0.3-0.4 ratio of spawning habitat to adult habitat recommended for productive marshes (Inskip, 1982). Based on these calculations, an additional 26-36 ha of suitable spawning habitat are required to sustain 90 ha of adult pike habitat.

Wildlife in Hamilton Harbour/Cootes Paradise

Undoubtedly, the loss of marsh habitat has had a profound effect on the composition, distribution and/or abundance of wildlife communities in Cootes Paradise and Hamilton Harbour. Waterfowl, rails, grebes, muskrats, bullfrogs, are all highly dependant on wetland vegetation for food, shelter, loafing and nesting. In 1979, the shoreline marshes of Hamilton Harbour and Cootes Paradise were estimated to have been reduced by 74% over the past 150 years (Whillans, 1982). A further reduction in marshes has occurred since 1979. An estimate of 50 hectares of the original 500 hectares would probably represent the 1985 status. While the impact of these habitat reductions on wildlife in both Cootes Paradise and Hamilton Harbour is currently only partially understood and documented, the available information that many marsh-dependant wildlife species have either declined or have completely died out.

The effect of toxic chemicals, particularly heavy metals and PCB's, on resident wildlife is difficult to ascertain.

Poor water clarity may be posing problems for visual feeders, though evidence of this is largely inferential. Ospreys feeding in the Harbour rarely, if ever, catch prey other than highly visible goldfish. Many adaptable species, mainly scavengers, have benefitted from habitat alterations and, now, numerically dominate the resident wildlife community structure.

More importantly, migratory species, in addition to being exposed to the cumulative effects of contaminants, must cope with a dwindling and vital food supply during migration. Surveys by CWS indicate that the remaining marshes along the Lake Ontario shoreline are extremely valuable as waterfowl concentration areas in spring and fall (Dennis and Chandler, 1974). Therefore, it is apparent that any efforts to expand food production in the remaining marshes will have a beneficial affect on waterbirds.

The major concerns for wildlife in the eastern Harbour area are: 1) the occurrence of heavy metals and toxic organics in the sediments of Windermere Basin, in the surficial sediments of the Harbour and the confined disposal facilities (CDFs) of the Hamilton Harbour Commission; 2) the impact of these contaminated sediments upon wildlife; 3) the future development plans (resulting in habitat loss) for Windermere Basin and areas known locally as the Hydro Islands and Pier 27.

It is paradoxical that some populations of water birds congregate in the east end of Hamilton Harbour where the sediments are known to be contaminated with organics and heavy metals and the habitat has deteriorated to a point where it is substandard at best. They breed in the area in large numbers during the spring and are attracted to the area in large numbers for migrational staging and overwintering. Wildlife in this area has been shown to accumulate high levels of contaminants and to suffer significant health problems. Many of the birds ingest highly contaminated food and at least two "die-offs" of ducks have been documented where lead poisoning seems to have been the most likely cause (Weseloh, CWS; McLarty, MOE pers.comm.). The area produces or has the potential to produce contaminated birds and other wildlife and this condition should not be allowed to persist.

In the early 1970s, HCB was found for the first time in the tissue and eggs of birds in Common Terns nesting on the Hydro Islands (Gilbertson 1972). At the same time, there was a high incidence of deformities among Common Tern chicks produced on the Hydro Islands (Gilbertson, et al 1976). In the early 1980s, eggs and young of Herring Gulls nesting at Pier 27 had elevated levels of both organics and heavy metals, when compared to Great Lakes samples (CWS, unpubl., Struger et al. 1987). However, the recent

breeding success of several colonies of fish eating birds in the Harbour, including Common Terns is cause for guarded optimism.

Concerning habitat loss in the eastern Harbour, the dredging plan for Windermere Basin seems to be evolving in a manner that will provide for wildlife concerns. Continued consultation with wildlife biologists and the naturalist community remains essential. At Pier 27, property owned by the Hamilton Harbour Commissioners, the future is not yet as assured. The Commissioners have said that they have no plans for the area for the immediate future, i.e. 10 - 15 years. However, eventually they will want to put warehouse facilities, or some similar development, on the site. That development will almost certainly displace the nesting colony of some 25,000 pairs of gulls, terns, herons and cormorants which currently breed there. The question is, given the long lead time before development is to take place, could the birds be encouraged to move to some other nearby, man-made or natural, nesting area? And if so, where, when and how? Less desirable species, like Ring-billed Gulls, will almost certainly move with little or no problem. However, for other species which are more sensitive to disturbance, e.g. Caspian Terns, there is no known precedent for "moving" them from one site to another.

Trends in the Hamilton Harbour Fishery

Historically, Hamilton Harbour was one of the most diverse and important fish habitats in western Lake Ontario. The outer Harbour, connected to Lake Ontario by the Burlington Ship Canal, supported a coldwater fishery dominated by lake trout, whitefish, and lake herring. Prior to 1800, the fishery also included Atlantic salmon and lake sturgeon. Kerr and Kerr (1860-1898) reported seasonal feeding migrations of lake trout and whitefish into Hamilton Harbour in June and July. Summer feeding migrations were followed by spawning runs in October and November as millions of whitefish and lake herring entered the Harbour to spawn on gravel shoals along the north and west shores (Holmes and Whillans, 1984). The commercial catch of lake herring in the late 1800's represented 48 percent of the western lake fishery and made up 15 percent of Lake Ontario's total commercial catch.

Cootes Paradise and the south and west shores of Hamilton Harbour consisted of shallow water marshes that provided spawning, nursery, and adult habitats for the warmwater fish community. Pike and bass were the dominant recreational and commercial warmwater species. Approximately 12270 kg of pike were taken by the commercial fishery in 1871 and bass fishing peaked in 1879 with a record catch of 5400 kg (Holmes and Whillans 1984). These catches do not include the large sport fishery (primarily spearing) for pike and bass in the north western end of the Harbour near Carrolls point. Whillans (1977, cited in Holmes and Whillans, 1984) estimated the annual mortality from spearfishing at 18000 kg/year. The diverse warm

water fishery included pike, bass, yellow perch, sunfish, muskellunge, walleye, drum, burbot, channel catfish, brown bullhead, and white sucker.

Decline of the Fishery

By 1900, the cold water fishery was responding to deteriorating water quality, competition from invading species (smelt), overfishing, and habitat loss associated with urban and industrial development. The first collecting sewer for the city of Hamilton was completed in 1854 (Threader et al. 1988). Prior to this, sewage disposal from 'water closets' emptied directly into Cootes Paradise and Hamilton Harbour and the combined effects of eutrophication, agricultural expansion, and industrial development were reflected by the Harbour fisheries. Commercial catches of lake trout, whitefish, and herring peaked at 4500, 13600 and an impressive 114000 kg per year, respectively, in the late 1800's. By 1950, annual catches of lake trout, whitefish and herring had dwindled to 0, 181, and 68 kg, respectively.

Stresses Affecting the Cold Water Fishery

The coldwater fishery in Hamilton Harbour responded to a number of stresses including overfishing, competition from newly introduced species, and deteriorating water quality (Whillans, 1979). Seining at the canal during feeding and spawning migrations, combined with heavy gill net fishing, substantially reduced lake trout, whitefish, and herring populations (Whillans, 1979). In addition, cold water species were unsuccessfully competing with smelt for benthic invertebrates (Pontoporeia, and sphaerids). Smelt were first reported in Hamilton Harbour in 1865 (Whillans, 1979) and were thought to be an important factor contributing to the decline of whitefish populations in the eastern basin of Lake Ontario (Christie, 1973).

There are few historical references describing the effects of eutrophication and toxic chemicals on the coldwater fishery. Whillans (1979) cites references from Kerr and Kerr, the Fisheries overseers from 1860-1898, describing deteriorating water quality on lake sturgeon spawning beds along the south shore and other instances of dead fish in close proximity to industrial discharges. Although warm water fisheries declined after the installation of the first collecting sewer in 1854, there were no data describing the effects of eutrophication on the hypolimnetic waters of the Harbour. Excessive nutrient inputs to the Harbour encourage algal production. The decaying algae and oxygen demanding sediments combine to deplete the dissolved oxygen in the hypolimnion during the summer months. This effectively eliminates the deep water habitat necessary to sustain the cold water fishery. Analyses of sediment core samples are underway to determine when this cycle of anoxia began in the Harbour and if this period of reduced oxygen coincided with the loss of benthic invertebrates and coldwater fisheries.

Stresses Affecting the Warm Water Fishery

The collapse of the coldwater fishery was quickly followed by a rapid decline in the number of warmwater fish and a transition from a predator dominated fishery to one dominated by forage species. Overfishing, toxic discharges, introductions of exotic species (carp, alewife, and white perch) and habitat loss were the major factors responsible for reductions in the warmwater fishery. These changes paralleled the growth of Hamilton as an industrial and urban centre. The city's population increased from 3,000 in 1840 to 25,000 by 1857 and reached 155,000 in 1931 (Threader et al., 1988). Population increases were accompanied by rapid industrial expansion along the south shore of the Harbour. By 1880, Hamilton was already established as a major iron manufacturing centre and in 1910, the steel producers merged to become the Steel Company of Canada. International Harvester expanded in 1911 and Dofasco, the second steel mill to be built on the south shore of Hamilton Harbour, was established in 1912. The Harbour was now receiving effluents from three municipalities, two of Canada's largest steel producers, and textile, rubber, paint, and solvent manufacturers. The Fisheries Overseer reported many occurrences of dead and dying fish along the vegetated shoreline (Whillans 1979).

The war years from 1915 to 1918 were accompanied by escalating steel and munitions production in Hamilton. Expanding industries required more land on the south shore and many of the shallow water marshes were filled to provide roads, docks, and factories. This trend continued in the post-war years and by 1959, approximately 22 percent of the open water area in the Harbour had been lost to landfilling (Threader et al., 1988). Although land reclamation along the south shore significantly reduced the open water area (and the retention time of the basin), the most significant impact was the loss of the shallow water marsh habitats that supported the warm water fish community. Prior to industrial development, the 43 km south shore was a complex marsh ecosystem colonized by emergent and submerged vegetation. The irregular shore line was inundated with inlets that in some cases created long bays extending more than 1 km inland. Landfilling reduced the total littoral shoreline from the 65 km available in 1800 to 17.3 km by 1985 (Figure 1). Most of the south shore has been dredged to at least 8 m deep. The landfilled shore is separated from the Harbour by steeply sloped berms or by vertical pilings. There is no suitable fish habitat along the south shore of Hamilton Harbour east of the former Lax property.

The loss of marsh habitat significantly reduced the abundance and distribution of warmwater fish. Disappearing wetlands along the south shore restricted the fishery to the north and west shores of the Harbour and to Cootes Paradise. However, habitat changes were not confined to Hamilton Harbour. The Cootes Paradise marsh was showing signs of stress. Emergent

vegetation, once abundant throughout the marsh, declined rapidly between 1934 and 1985 (Table 22).

IV.3.4.2 Contaminants in Biota

Algae

The biological availability and toxicity of sediment metals have not been adequately tested. Analyses of algae suggested elevated levels of copper, chromium and nickel relative to sediment concentrations. However, these metals may be regulated as nutrients, i.e. they may be actively scavenged from water or excessive levels may be excreted. Concentrations of cobalt, zinc, and lead in algae were lower than in sediments.

Benthic Invertebrates

Benthic worms in Windermere Basin contained 2 - 6 times more PCB, chlorinated pesticides and hexachlorobenzene (HCB) than did the sediments they were associated with (Persaud et al. 1987).

Turtles

In a study of organochlorine levels in snapping turtle eggs from 10 sites in southern Ontario, eggs from Hamilton Harbour had the highest levels of PCBs (8.59 ppm, wet weight), oxychlordane (0.074 ppm), trans non-achlor (0.02 ppm) and dieldrin (0.06 ppm) (Struger et al, 1987). The significance of the contaminants in the snapping turtles is unknown; although in another study, hatching deaths and deformities were correlated with levels of chlordane (Bishop, pers.comm.). Hatching deaths and deformities were examined at five sites (Hamilton Harbour, Lynde Shores Creek (Whitby), Cranberry Marsh (Whitby), Long Point (Lake Erie), and Algonquin Park). Hatching deaths were approximately 40% at both Hamilton Harbour and Lynn Shores Creek compared to 10% at the other sites. Deformities, however, were highest at Cranberry Marsh (28%) compared to the other sites (0-2%). In 1986, snapping turtle egg contents from Hamilton Harbour were found to be significantly more contaminated with the pesticides pp'DDE, HCB, α -chlordane and trans-nonachlor than those from Long Point, Algonquin Park and Cranberry Marsh. However, the HCB and PCB concentrations in eggs from Hamilton Harbour and Lynde Shores Creek were similar. This suggests that turtles in sites such as Hamilton Harbour and Lynde Shores Creek, which are connected to Lake Ontario, are subject to contaminants from the Lake.

Fish

Until 1985, sport fish collected from Hamilton Harbour for contaminant analysis had been, with a few exceptions, limited in numbers of specimens of any single species caught. In 1985, large collections were obtained, and at the present time, analyses has been completed for most of the parameters specified.

Review of these results will enable the consumption advice contained in the 1987 Guide to Eating Ontario Sport Fish to be upgraded from the five species given there (Rainbow Smelt, White

Perch, Brown Bullhead, Carp and Northern Pike) to twelve species (Rainbow Smelt, White Perch, Brown Bullhead, Carp, Northern Pike, Black Crappie, White Sucker, Yellow Perch, White Bass, Channel Catfish, Brown Trout and Freshwater Drum). The revised consumption advice will be contained in the 1988 edition of the guide.

Five of the twelve species have limitations on consumption of some sizes of those fish. One species is advised for restricted consumption at all sizes sampled, and seven species do not have any advised consumption limitations placed on them.

Consumption limitations arise from the presence of one or more of three contaminants: mercury, PCBs, and Mirex.

Mercury levels in Freshwater Drum (Sheepshead) were found to average 0.56 ppm, ranging between 0.16 and 1.2 ppm. Statistical projection indicates that this species would exceed 0.5 ppm mercury in the 35 to 45 cm size range, and would also exceed 1.0 ppm mercury in the 45 to 55 cm size range. Assessment of the organic contaminant data for this species showed Mirex levels were calculated to exceed the 0.1 ppm Federal guideline in the 45 to 55 cm size range of fish in this sample, resulting in further advised restrictions on the consumption of large Freshwater Drum.

In the case of the consumption advice on White Perch, both PCB and Mirex were found to exceed the respective Federal guidelines of 2.0 ppm PCB and 0.1 ppm Mirex in the 25 to 30 cm length range. While in this same sample, mercury was calculated to exceed the 0.5 ppm guideline in the 30 to 35 cm size range, this exceedence is over-ridden by the exceedences for PCB and Mirex.

Carp over 65 cm in length are advised for restricted consumption based on the projection that PCB will exceed 2.0 ppm in specimens between 65 and 75 cm in length.

While the sample of Channel Catfish was small, the PCB and Mirex levels in nearly all individuals exceeded the Federal guidelines. For this reason, all sizes of Channel Catfish from Hamilton Harbour are advised for restricted consumption only. This includes specimens in the length range from 20 to 65 cm.

In the case of Brown Trout, again, a species collected only in small numbers, most of the fish collected exceeded the Federal guideline for mire. Calculations indicated that Brown Trout from 45 to 65 cm would exceed 0.1 ppm Mirex. Brown Trout in the size range collected were calculated not to exceed the 2.0 ppm PCB or 0.5 ppm mercury guidelines.

The other seven species (Rainbow Smelt, Brown Bullhead, Northern Pike, Black Crappie, White Sucker, White Bass and Yellow

Perch are considered as suitable for consumption in regard to Federal guidelines for mercury, PCB, Mirex and DDT.

More recent data were collected in 1987 by Fisheries and Oceans. Composite whole fish samples of carp, white perch, brown bullheads, and white suckers (two pooled samples of 10 large and 10 small fish of each species) were analyzed in 1987. The results indicate that carp and white perch in Hamilton Harbour are accumulating PCB's. Concentrations of Mirex, DDT, DDE, HCB, Chlordane, Dieldrin, and Endrin were below consumption advisory levels. PCB accumulation in carp occurs at several other sites on Lake Ontario and consumption advisories (based on PCB's, Mirex and pesticides) are in effect at five of the nine sites sampled in Lake Ontario and the St. Lawrence River (MOE, 1987).

While fish have accumulated trace organics, the levels in edible portions (muscle) have declined steadily between 1972 and 1981 and have been lower than observed in fish from Lake Ontario. Table 25 illustrates the earliest record and the latest record for PCB concentrations in Hamilton Harbour fish. Major reductions in the PCB content have occurred.

Table 25: PCB concentrations in Fish from Hamilton Harbour
Earliest Record 1981

Fish	Concentration (mg/kg wet)	Fish	Concentration
Pike	-	Pike	0.49
Carp 1976	8.9	Carp	0.02
Bullheads 1972	4.0	Bullheads	0.04
Yellow Perch 1976	0.52	Y. Perch	0.1
White Perch 1978	1.13	W. Perch	0.42
Sunfish 1972	2.5	Pumpkinseed	0.02

Consumption Guideline is 2 mg/kg

The source of contaminants accumulating in Hamilton Harbour fish is complicated by seasonal movements between the Harbour and the lake. At least 15 species, including Pacific salmon, lake trout, rainbow trout, brown trout, white perch, white suckers, yellow perch, American smelt, white bass, freshwater drum and carp, migrate into the Harbour and Cootes Paradise from Lake Ontario. Some species, such as carp and white perch, remain in the Harbour (and Cootes) from May-November and contaminant burdens during this period of maximum feeding are strongly influenced by local conditions. Trout and salmon enter the Harbour for short periods in the spring and fall and contaminant burdens in these species are more representative of Lake Ontario exposure. Consumption advisories for salmon and trout are in effect at most sites on Lake Ontario.

Studies of blood lead levels have demonstrated little difference between Hamilton Harbour fish and those from other

parts of the Great Lakes. In fact, fish from Toronto Harbour and other Lake Ontario locations were more contaminated. This was true even for benthic feeding species which generally accumulate more lead than pelagic feeders.

Tissue levels of PCBs and other organochlorines in white suckers from Hamilton Harbour were similar to levels in suckers from several sites along the north shore of Lake Ontario (Table 26). These data suggest that contaminants in Hamilton Harbour fish, particularly non-resident species, are strongly influenced by Lake Ontario. Tissue burdens in non-migratory Harbour predators such as pike and bass are also affected by Lake Ontario contaminants. Migrating alewife, smelt, white perch, and yellow perch, are important food for resident fish. Hurley, (1986) reported that these species constituted 76 percent of the northern pike diet in the Bay of Quinte.

Concerns for an edible fishery in Hamilton Harbour must be addressed on a whole lake basis. Many of the non-resident species such as smelt, alewife, salmon and trout accumulate contaminants lake wide and it is unlikely that reduced loadings in Hamilton Harbour will result in an edible non-resident fishery.

Table 26: Organochlorine concentrations (mg/kg) in whole white suckers from several sites on Lake Ontario, 1983.

	Hamilton	Bronte	Humber	Ganaraska	Brockville
# of fish	18	5	9	5	5
PCB	1.52 ±0.42	1.92 ±1.45	3.39 ±1.22	1.24 ±0.76	1.88 ±1.77
EDDT	0.34 ±0.12	0.79 ±1.26	0.53 ±0.29	0.29 ±0.16	0.03 ±0.03
HCB	0.01 ±0.01	0.01 ±0.01	0.01 ±0.01	0.09 ±0.09	0.01 ±0.00
Mirex	0.06 ±0.05	0.05 ±0.01	0.04 ±0.03	0.06 ±0.04	0.09 ±0.07
DIELDRIN	0.02 ±0.02	0.02 ±0.02	0.03 ±0.02	0.02 ±0.00	<0.01
αCHLORDANE	0.004 ±0.002	ND	ND	ND	ND

Note Fish from Hamilton, Bronte, Ganaraska, and Brockville were 5-7 year old males. Humber River fish were 5-7 year old females.
Source V.W. Cairns Department of Fisheries and Oceans

Fish Health in Hamilton Harbour

Fish tumour surveys conducted in Hamilton Harbour between 1973 and 1976 (Sonstegard, 1977) reported the occurrence of epidermal tumours on white suckers and brown bullheads and

gonadal tumours on carp, carp X goldfish hybrids, and goldfish. Sixty percent of the five year old carp X goldfish hybrids collected in 1975 were affected with benign gonadal tumours. The tumour does not occur on fish less than 4 years old and increases with age until almost 100 percent of the older males are affected. All tumoured fish are sterile and all hybrids (tumoured and non-tumoured) are sterile. Sampling at other sites revealed that the tumour also occurred in hybrids from upper Lake Huron (Kincardin), Rochester, Long Point on Lake Erie, and Detroit suggesting that gonadal tumours on carp X goldfish hybrids are ubiquitous throughout the Great Lakes. Fifty-two percent of the 5 year old fish collected in 1983 had benign gonadal tumours indicating almost no change from the 60 percent observed in 1975 (Table 27).

Sonstegard also reported the occurrence of benign papillomas on the lips of white suckers (Sonstegard 1977) and benign and malignant epidermal tumours on the lips and bodies of brown bullheads (Sonstegard 1976). The frequency of occurrence of white sucker lip papillomas increased in urban environments at the western end of Lake Ontario (35% in Hamilton Harbour, 50% occurrence in Sixteen Mile Creek) (Sonstegard 1977). Papilloma surveys in 1983 indicated almost no change in prevalence in Hamilton Harbour and Sixteen Mile Creek between 1973 and 1983 (Table 28). However, lip papilloma frequency increases with age and comparisons between the 1983 and 1973-76 data may not be valid since sample size and fish age were not reported for the 1973-76 collection. Based on the 1983 survey it appears that the frequency of occurrence in Lake Ontario ranges from 5 to approximately 60 percent with prevalence exceeding 30 percent at all sites along the north shore to the west of Toronto and in the area of Port Hope (Gage Creek) (Table 29). This supports Sonstegard's observation of a high prevalence of lip papillomas in urban areas of western Lake Ontario.

The cause of epidermal papillomas on white suckers is unknown. Papillomas occur on white suckers throughout the Great Lakes, although prevalence appears to be elevated in urban areas. White suckers from non-urban environments in northern Lake Huron had a low prevalence of lip papillomas compared with fish from Lake Ontario (the prevalence in fish 8 years and older from the Serpent River and South Bay was 0 and 5 percent, respectively. The widespread distribution of the papilloma at low levels (less than 15 percent) suggests an infective process and is consistent with the the observation by Sonstegard (1977) that a C type virus is associated with the papilloma.

The papilloma has no noticeable effect on the biology of white sucker populations in Hamilton Harbour. Spawning migrations were monitored in Grindstone Creek from 1980 to 1983. All year classes were represented in the population and there was no significant difference in growth, fecundity, fertility,

percent hatch, fry survival and growth, or reproductive behaviour between normal and papillomatous fish (Cairns and Fitzsimons 1988). The tumour may remain on the fish for long periods in the wild (several had not changed in two years) but may develop rapidly (one fish developed 3 large tumours within 2 months). Papillomas tend to shrink when the fish are held in a laboratory environment suggesting that a biological or chemical agent is necessary to sustain it.

The prevalence of lip papillomas in brown bullheads from Hamilton Harbour declined from 80 percent in 1973-76 (sample size unknown) (Sonstegard 1976) to 25 percent in 1983 (Table 27). The prevalence of lip papillomas in bullheads from the Harbour is similar to that reported by Baumann (1987) for bullheads from the heavily polluted Black River in Ohio and from Lake St. Clair (Cairns pers comm). Grizzle (198??) determined that lip papillomas were caused by exposure to chlorinated sewage effluents and Black (198?) was able to induce papillomas by repeated applications of Buffalo River sediment extracts. Both of these studies suggest a possible chemical (irritation?) etiology. Body lesions, which occur less frequently than lip papillomas, appeared as flat, circular, black or brown plaques, or as raised black or brown, single or multi-nodular growths. The plaques are benign epidermal hyperplasia and were not included in the estimates of body tumours reported in Table 27. Histological analysis of 17 of the 33 observed growths found 10 of the 17 to be invasive carcinomas (Cairns and Fitzsimons 1988). The remainder were diagnosed as benign papillomas. In addition, 72 percent of the barbels (used for sensory stimuli) were short stubby projections less than 5 mm in length. In some fish the barbel ended in a swollen mass. There are no data from other locations reporting the significance of this finding. However, the occurrence of ulcers and finrot resulting from contact with contaminated sediments (by infectious or chemical agents) has been reported for marine species (Sherwood and Mearns 19??).

In addition to epidermal papillomas, white suckers from Hamilton Harbour were also affected with liver (cholangiolar and hepatocellular) lesions. These included hyperplasia and several different types of carcinomas. The prevalence of total liver neoplasms was highest in Sixteen Mile Creek (10.1%) and lowest in Forty Mile Creek (0.7%) (Table 30). Surprisingly, white suckers from the control site on Manitoulin Island had a 3.5 percent prevalence of cholangiolar carcinomas. An additional survey conducted in 1987 (Cairns and Fitzsimons, 1988) observed cholangiolar carcinomas in white suckers from eight sites tested on Lake Ontario (the prevalence ranged from 0.7 percent at Forty Mile Creek to 9.2% in the Ganaraska/Coburg Rivers). The occurrence of cholangiolar lesions at all sites suggests a background prevalence of cholangiolar anomalies in white suckers from the Great Lakes. Hepatocellular tumours were found only in white suckers from Hamilton Harbour, Sixteen Mile creek, and the

Humber River. Analysis of Hamilton Harbour sediments revealed the presence of mammalian carcinogens (PAHs). A tumour induction experiment was conducted in which Hamilton Harbour sediment extracts were injected into the yolk sacs of developing rainbow trout fry. Twelve percent of the fry developed tumours within 14 months following a single exposure (Metcalfe, Cairns and Fitzsimons, 1988). Although chemical exposure to carcinogens in the Harbour are complicated by availability, fish movement, routes, and susceptibility of the host, the induction trial combined with the chemical analysis suggests a potential for carcinogenesis.

Table 27 Summary of lesions reported in Hamilton Harbour fish

SPECIES	LESION	PREVALENCE (N)
WHITE SUCKER		
lip	lip neoplasia	39 (1200)
skin	skin neoplasia ^a	2.3 (1200)
	hyperplasia	0.6 (1200)
	papilloma/carcinoma	1.7 (1200)
liver	liver neoplasia ^b	4.3 (113)
	carcinoma	2.7 (113)
	adenoma	0.8 (113)
	melanohistiocytoma	0.8 (113)
	granuloma	4.4 (113)
gonad	testicular lesions ^c	4.2 (71)
	seminoma	1.4 (71)
	hypertrophy	2.8 (71)
bladder	fibrosarcoma	1 (113)
BROWN BULLHEAD		
lip	lip neoplasia	25.4 (480)
skin	body neoplasia ^d	7 (480)
	barbel asymmetry	72 (480)
	ulcer	5 (480)
liver	gross anomalies ^e	10.5 (380)
	cholangiolar carcinoma	1.6 (124)
GOLDFISH		
skin	ulcer ^f	50-80 N/A
kidney	granuloma ^f	51 (29)
	polycystic	6.3 (80)
gonad	neoplasia	30 (13)
CARP		
gonad	neoplasia	0.9 (220)

Table 27 (cont.) Summary of lesions reported in Hamilton Harbour fish

SPECIES	LESION	PREVALENCE (N)
CARP X GOLDFISH		
gonad	neoplasia	52 (79)
	hermaphrodisism	6.3 (79)
WHITE PERCH		
kidney	glomerular nephritis	100 (43)

- a Total skin lesions.
b Total liver lesions.
c Total testicular lesions.
d Total number of raised papillomas/carcinomas.
Of the 33 observed body neoplasms, 17 were analyzed. Ten of these were diagnosed as squamous cell carcinomas and the remainder as benign papillomas.
e A total of 380 livers were observed. One hundred and twenty-four were analyzed histologically. Two were diagnosed as cholangiolar carcinoma.

TABLE 28 Temporal changes in the prevalence of lip papillomas in Lake Ontario white suckers from 1973-76^a to 1983^b

LOCATION	PERCENT OCCURRENCE	
	1973-76 ^c	1983 ^d (N)
Grindstone Creek	35.1	39 (1200) ^e
Toronto	2.2	40(58) ^f -16(96) ^g
Sixteen Mile Creek	50.8	62 (111)
Jordan Harbour	8.0	23 (132) ^h -9(132) ⁱ
Rochester	0.8	no data

- a Sonstegard, 1977 b Fisheries and Oceans Canada
c fish age and sample size not reported
d mean prevalence for fish 7 years of age and older
f Humber River g Rouge River
h Forty Mile Creek i Vineland

TABLE 29: Summary of lip and body neoplasms¹ in white suckers from Lake Ontario. Data from 1981 to 1983.

SITE	LIP ² (N)	BODY ³ (N)
VINELAND	9 (132)	0
FORTY MILE CREEK	23 (78)	2.5 (155)
GRINDSTONE CREEK	39 (1200)	1.4 (5284)
SPENCER CREEK	71 (146)	2.7 (146)
BRONTE CREEK	54 (109)	2.1 (147)
SIXTEEN MILE CREEK	62 (111)	9.4 (160)
CREDIT RIVER	34 (38)	2.5 (118)
HUMBER RIVER	40 (58)	0.8 (335)
ROUGE RIVER	16 (96)	0.3 (347)
GRAHAM CREEK	19 (102)	5.0 (119)
GAGE CREEK	40 (99)	4.1 (192)
COBURG CREEK	15 (102)	2.7 (146)
BAY OF QUINTE	5 (91)	2.7 (184)
BROCKVILLE	15 (177)	7.8 (192)
Lake Huron		
Maitland River	40 (N/A)	N/A
South Bay	5 (280)	N/A

- 1 Neoplasms refer to single or multi-nodular growths. They do not include obvious flat grey patches of hyperplasia. Not all of these lesions were confirmed histologically.
- 2 Mean percent occurrence for fish 7 years and older.
- 3 Mean percent occurrence for combined ages.

Table 30: The occurrence of liver tumours in white suckers from Lake Ontario and McLellan Creek on Manitoulin Island.

SITE (N)	PREVALENCE (%)	
	CHOLANGIOLAR	HEPATOCELLULAR
FORTY MILE CREEK (134) ^a	0.7 carcinoma	0 carcinoma
HAMILTON Harbour (113)	1.7 carcinoma 1 melanohistiocytoma	0.9 carcinoma 0.9 adenoma
SIXTEEN MILE CREEK (612) ^b	7.0 carcinoma	1.5 carcinoma 1.6 adenoma
M ^C LELLAN CREEK (228)	3.5 carcinoma	0 carcinoma

a Sample size

b Only 554 of the 629 fish were examined histologically. The remaining 75 fish had no apparent anomalies. All fish were collected during the spring spawning runs of 1984 and 1985.

c Control site located at McLellan and High Creeks on Manitoulin Island

Birds

The earliest studies of contaminants in birds from Hamilton Harbour date from 1970 when Gilbertson (1972) reported HCB, dieldrin, DDE and PCBs in Common Tern (*Sterna hirundo*) eggs from the Hydro Islands. This was the first reported instance of HCB in avian tissue. In 1971, Gilbertson (1974) conducted further investigations which showed that the terns which nested on the Hydro Islands returned in the spring relatively free of contaminants but the residue levels in their eggs increased as the dates of laying became later. Eggs laid in June had higher contaminant burdens than those laid in May. He also discovered deformities, suspected of having been mediated by contaminants, among terns nesting on those islands (Gilbertson et al. 1976).

Few studies were conducted within the Harbour itself during the remainder of the 1970s. In the 1980s, Herring Gull eggs from the Harbour were sampled in 1981, '82, '84 and '86. Results of these studies showed that levels of most contaminants were greatest during the earlier sampling period. In 1981, DDE, PCBs and Mirex levels were 11,79 and 1.9 ppm (wet weight), respectively. In 1986 (87), those same contaminants were 4.0, 25 and 0.71 ppm (C.W.S. unpubl.): a reduction of 63 - 68% (CWS, unpubl.).

In 1981/82, a Lake Ontario wide survey was done of contaminant levels in Herring Gull eggs. Eggs from 8 Lake Ontario sites, including Hamilton Harbour, showed no significant variation in contaminant levels among sites (except for one compound at one site) (Weseloh & Struger 1985). In other words, contaminant levels in Herring Gull eggs from Hamilton Harbour were neither significantly higher nor lower than those from other Lake Ontario sites. In a 1983 study of lead, cadmium and mercury levels in Herring Gulls from four Great Lakes sites, adult gulls from the eastern Harbour had the highest levels in 25% of the cases. Kidney levels of lead and cadmium were 6.90 and 2.16 ppm (wet weight), respectively, and liver levels of mercury were 1.36 ppm (Struger et. al 1987). It should be noted that levels in gulls probably represent the integration of levels in food from distances within 5 - 10 miles from the colony site. Thus levels in Hamilton Harbour gulls are not indicative of only Hamilton Harbour.

A die-off of wild waterfowl occurred in Windermere Basin in March, 1986 (A. McLarty, MOE, Pers. Comm.). In a 1986 study of flightless, domestic ducks released into Windermere Basin and two other sites, those at Windermere accumulated PCB residues almost 50 times greater than ducks at the other locations. Lead levels were also greatly elevated in Windermere Basin birds compared to those from the other sites. There are strong suggestions that lead was the prime causative factor in the die-offs of both the domestic ducks and the earlier case involving wild ducks at Windermere (CWS and MOE, unpubl., respectively).

V IDENTIFICATION OF POLLUTANT SOURCES

V.1 POINT SOURCES

V.1.1 Municipal

Four municipal sewage treatment plants (STPs) discharge treated wastes to Hamilton Harbour. All four plants are well operated.

The Woodward Avenue plant in Hamilton is the largest serving a population of about 360,000. Sewage from the cities of Hamilton and Stoney Creek and the Town of Ancaster is treated at the plant. It has a design capacity of 409,000 cubic metres per day and is now treating about 320,000 cubic metres per day. It is a conventional activated sludge sewage treatment plant with chemical treatment for phosphorus removal. The treated effluent is discharged to Redhill Creek as it flows into Windermere Basin of Hamilton Harbour.

The Skyway plant in Burlington serves a population of about 120,000. The sewage from the total urban area of Burlington is treated at the plant. It has a design capacity of 93,000 cubic metres per day and is now receiving about 71,000 cubic metres per day. It is a conventional activated sludge plant with chemical treatment for phosphorus removal. The treated effluent is discharged into the northeast corner of Hamilton Harbour.

The Dundas plant treats the sewage from a population of about 19,500. The plant has a design capacity of 18,000 cubic metres per day and is now treating a sewage flow of about 11,000 cubic metres per day. It is a conventional activated sludge plant with chemical treatment for phosphorus removal. Sand filters are now being installed to further treat the final effluent. Installation of the filters will be completed in 1988. The treated effluent from the plant is discharged to Cootes Paradise.

The Waterdown plant serves a population of about 4,000 and is treating the sewage from the Community of Waterdown. The plant has a design capacity of 2,730 cubic metres per day and is now treating a sewage flow of 2,400 cubic metres per day. It is a conventional activated sludge plant operating in the extended aeration mode and has chemical treatment for phosphorus removal. It has sand filters for polishing the final effluent. The treated effluent is discharged to Grindstone Creek.

V.1.2 Industrial

The two steel mills discharge treated wastewaters to the Harbour. Small quantities of uncontaminated cooling water are discharged by several smaller industries located near the Harbour. All other industries discharge their wastewaters to the municipal sewers for treatment at the municipal sewage treatment plants.

Stelco discharges about 1,040,000 cubic metres per day of treated effluents to the Harbour through eight outfalls. Dofasco discharges about 640,000 cubic metres per day of treated effluent through four outfalls. Control facilities installed by the steel mills include ion exchange for chromium removal, chemical treatment plants for oil and solids removal, steam distillation for ammonia removal, biological treatment for phenols and cyanide removal, clarifiers and dual media filters for suspended solids removal and recirculation to reduce flows and, therefore, effluent loadings. These control facilities have been found to be efficient in removing priority pollutants as well as the conventional parameters.

V.1.3 Combined Sewer Overflows (CSOs)

Sewage and storm water runoff are collected in a combined sewer system in most of the City of Hamilton. As a result, during periods of high runoff the combined sewer system becomes overloaded and raw sewage overflows into the receiving waters at 26 locations. The Regional Municipality of Hamilton-Wentworth has installed a holding tank at the largest of the combined sewer overflows to collect the sewage overflow. After the runoff event the collected sewage will be diverted back into the sewer system for treatment at the municipal sewage treatment facility. The holding tank is designed to collect the total overflow during most summer storm events and to act as a primary clarifier during extended periods of runoff such as occur in the spring. This holding tank, which is located at the Greenhill Avenue combined sewer overflow, is expected to be placed in operation in 1988. Combined sewer overflows (86,000 m³/day) are a source of ammonia and phosphorus, bacteria and suspended solids. The estimated 1987 ammonia and phosphorus loading from combined sewer overflows are 200 kg/day and 90 kg/day, respectively.

V.1.4 Landfill

Landfill sites are thought to be an insignificant loading source to Hamilton Harbour.

Summary of Point Source Loadings

Municipal and industrial loadings of pollutants has been reduced by 60-95 % since the early 60's. The current (1985) loadings from the significant municipal and industrial point sources are summarized in Tables 31 and 32.

Table 31: BOD, Suspended Solids, Ammonia and Phosphorus Loadings
(kg/day)

	Stelco	Dofasco	Ham.	Burl.	Dundas	CSO's	Streams
Ammonia							
1985	156	590	5500	630		200	
1986	13	563	5547	811	{	211	}
1987	627	244	5300	1150	{	200	}
Phosphorus							
1985			399	47	7	78	80
1986			400	51	{	185	}
1987			292	42	5.6	78	107
BOD	2585	596	4627	559	{	3560	}
Suspended Solids	15464	11761	4786	469	{	33670	}

Table 32: Point Source Loadings (1985) to Hamilton Harbour
(kg/day)

	Priority Pollutant Source				
	Stelco	Dofasco	Hamilton	Burlington	Dundas
			STP	STP	STP
Flow(10 ³ m ³ /d)	1048	787	308	64.9	13.4
Acid					
Extractables	nd	nd	nd	nd	nd
Base Neutrals					
PAHs	1.05	0.76	0.02	0	0
others	4.1	11.8	nd	nd	nd
Organochlorine					
Pesticides					
PCBs	nd	nd	0.037	0.0012	0.0003
others	nd	nd	0.022	0.007	nd
Volatiles	0.0832	0.5512	nd	nd	nd
Cyanide	46.4	21.1	0	0	0
Heavy Metals	93.97	96.1	43.9	4.4	0.6
Phenols	31.4	8.0	2.26	0	0
Total Priority Pollutants	177	138	46	4.4	0.6

V.2 NON POINT SOURCE LOADINGS TO HAMILTON HARBOUR

V.2.1 Atmospheric

Using the deposition rates of various compounds (kg/km²/yr) from Kuntz (1980) and IJC Great Lakes Science Advisory Report (1980) for Lake Ontario and the Harbour's water surface, the atmospheric loading can be estimated. Table 33 summarizes the estimated atmospheric loading and compares it to the loadings from point sources. The atmospheric loadings have been calculated for only the Harbour's water surface. Stormwater runoff from the watershed will increase the contribution of atmospheric loading reported in Table 33.

Table 33 : Atmospheric Loadings (kg/day)

	Atmospheric	Point Source	%
Phosphorus	1.18	609	0.2
Ammonia	17.7	7076	0.2
Copper	0.24	9.2	2.6
Iron	4.4	7647	0.06
Lead	0.88	23.2	3.8
Zinc	3.5	189.5	1.8
PCBs	0.007	0.039	17.9
α -BHC	0.002	0.0016	125
γ -BHC	0.011	0.006	183
PAHs	0.116	1.8	6.4
DDT	0.0004	0.0041	9.7
Dieldrin	0.0004	<0.0002	>200
Endosulfan	0.006	na	-
HCB	0.001	0.0068	14.7

Atmospheric loadings for inorganic compounds are relatively insignificant. Atmospheric loadings of trace organics are significant relative to point source loadings. The relative importance of atmospheric loading to point source loading depends on the compound.

V.2.2 Agricultural

Very little is known of agricultural loadings to Hamilton Harbour. Relative to municipal and industrial loadings, agricultural loadings of contaminants are thought to be insignificant. Loadings of suspended solids from the watershed are important but the relative contribution of agricultural sources, urban and in-stream erosion sources is unknown. A land use survey is being conducted to provide this information.

V.2.3 Road Salt

The total loading of dissolved solids to Hamilton Harbour from all sources was estimated to be 607,000 kg/day in 1977 (Snodgrass, 1981). The use of road salt in 1976-77 was approximately 26×10^6 kg for Hamilton and Halton. Therefore, road salt represents approximately 12% of the annual load of total dissolved solids.

V.2.4 Shipping and Spills

Spills in the Harbour are a relatively minor source of pollution. Between 1974 and 1986, there were only seven significant ship-related incidents reported. One was of bunker "C" and the rest were of light oil, ranging from 0.1 to 3 metric tonnes in size. In all cases, 60-90% of the oil was recovered by skimmers and absorbants. Numerous slicks are observed, on the water but since oil spreads rapidly to a thin sheen, sometimes as thin as 1 molecule thick, these slicks represent very small quantities.

Spills from other sources are more frequent. During the same 12 years, sixty-four incidents from land based activities were reported. Half of these involved oil and the rest represented a wide variety of industrial liquids. The most commonly released product has been hydrochloric acid: a total of 950 metric tonnes in 8 accidents. Acids and some other chemicals mix easily with water and cannot be recovered.

The spill records kept by DOE since 1974 indicate the number and volume of spill incidents are dropping in response to tougher regulations and preventive and educational programs.

All spills from industries are investigated to determine the cause and to ensure that measures are taken to prevent a recurrence. As well, detailed hazardous operations analyses are being carried out to identify where things may go wrong so that preventative measures can be taken to minimize upsets.

V.3 IN SITU LOADINGS

Elevated concentrations of metals in the bottom waters of the Harbour due to release from the sediment to the water column has not been observed except for manganese and, occasionally, iron. Trace organic contaminants have a high affinity for sediment surfaces and are usually insoluble in water. Therefore, organic contaminants located in the sediments will also remain associated with the sediments and will not be released into the water column

V.3.1 Sediment Phosphorus Release

In many lakes, sediments release nutrients into the overlying water and this release can be the dominant nutrient flux (Ryding 1985). The Hamilton Harbour sediments are not presently considered an important source of nutrients to the water column. Phosphorus release from the sediments has not been observed in the Harbour (MOE, 1986), in short-term equilibrations with Harbour sediment (Mudroch and Sandilands 1980), or in long-term anoxic laboratory incubations with Harbour sediment (Burnison, personal communication). Sediment phosphorus release was observed in sediment cores that were bubbled with nitrogen or oxygen. The phosphorus release rates measured over a two month period were equivalent to one to two weeks of external loading of phosphorus. Currently, sediment phosphorus release is a minor source of phosphorus.

The high concentrations of nitrate or iron in the Harbour may account for this lack of an anticipated release of phosphorus from anoxic sediments. High iron concentrations have been found to reduce phosphorus release in anoxic sediments (Nordin, British Columbia MOE, personal communication).

V.3.2 Sediment Oxygen Demand

Mudroch and Sandilands (1980) found that ammonia was readily released from sediments into lake water but this release is probably insignificant relative to the external loading of ammonia. However, if the sources of ammonia to the Harbour are treated with the best available technology, then the sediment release of ammonia will become important in delaying the oxidation of the hypolimnion. Bacteria consume oxygen to oxidize ammonia.

The sediment oxygen demand accounts for a small portion of the total oxygen demand; 40% in spring, 10-20% in summer, and 25% in the fall (MOE, 1985). As the restoration of the Harbour proceeds, sediment oxygen demand will delay the oxygen response of the Harbour. Eventually, the sediments could become oxidized, but the period of time required for this to occur is unknown but an estimate of 10 years has been suggested.

V.4 SUMMARY OF LOADINGS BY CONTAMINANT

V.4.1 Hamilton Harbour

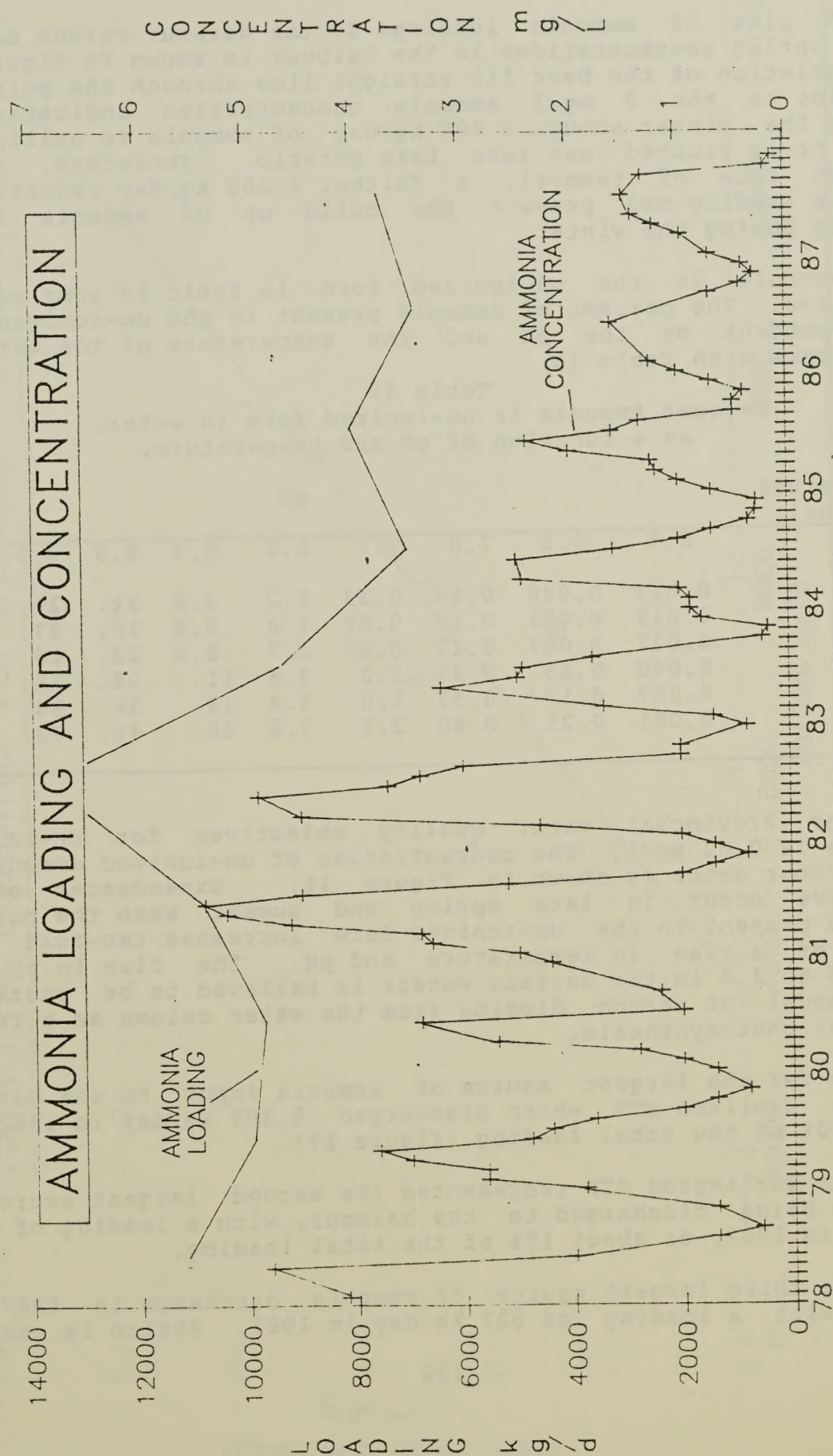
V.4.1.1 Ammonia Loading

Major reductions in industrial discharges of ammonia have been achieved. The industrial loadings have been reduced from about 24,000 kg/day of ammonia as nitrogen in 1967 to about 857 kg/day in 1987. However, there has been little change in the loadings of ammonia from the municipal STPs. Regular monitoring for ammonia in the effluents from the STPs was started in 1978.

Figure 14 shows the total loadings of ammonia as nitrogen from both industrial and municipal sources since 1978, including estimates of loadings in Hamilton's CSOs and the concentration of ammonia found in the Harbour. The concentration trend in the Harbour is cyclical with the highest concentration occurring in the early spring and the lowest in the summer. The cyclical pattern is caused by the inhibition of cold temperatures on nitrifying bacteria which oxidize ammonia. As a result, the concentrations build up in the Harbour during the winter. In 1987, the concentration peaked at 1.5 mg/l. When the water temperature warms above 6 C in spring, the nitrifying bacteria become active again and very rapidly oxidize the accumulated ammonia. In so doing, the oxygen level in the Harbour water is reduced. The oxidation of each mg/l of ammonia, as nitrogen, requires about 4.6 mg/l of oxygen.

Not all of the ammonia discharged to the Harbour is oxidized. Ammonia is also flushed to the lake through the canal. As well, some ammonia is used by the aquatic biota as a nutrient. It is initially taken up by aquatic plants, including algae, and by bacteria. A small portion of this nitrogen makes its way through the food chain, ending up as protein in fish and in water fowl.

Figure 14



A plot of ammonia loadings to the Harbour versus maximum early spring concentrations in the Harbour is shown in Figure 15. Extrapolation of the best fit straight line through the points in the plot to the 0 mg/l ammonia concentration indicates that during the winter about 3,600 kg/day of ammonia is utilized by algae or is flushed out into Lake Ontario. Therefore, at the present rate of removal, a further 4,200 kg/day reduction in ammonia loading may prevent the build up of ammonia in the Harbour during the winter.

Ammonia in the un-ionized form is toxic to some aquatic organisms. The percent of ammonia present in the un-ionized form is dependent on the pH and the temperature of the water in accordance with Table 34.

Table 34
Percent Ammonia in un-ionized form in water,
as a function of pH and temperature.

Temperature (Celsius)	pH								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.013	0.040	0.13	0.39	1.2	3.8	11.	28.	56.
10	0.019	0.059	0.19	0.59	1.8	5.6	16.	37.	65.
15	0.027	0.087	0.27	0.86	2.7	8.0	22.	46.	73.
20	0.040	0.13	0.40	1.2	3.8	11.	28.	56.	80.
25	0.057	0.18	0.57	1.8	5.4	15.	36.	64.	85.
30	0.081	0.25	0.80	2.5	7.5	20.	45.	72.	89.

The Provincial water quality objectives for un-ionized ammonia is 0.02 mg/l. The concentration of un-ionized ammonia in the Harbour water is shown in Figure 16. Exceedences of the objective occur in late spring and summer when the percent ammonia present in the un-ionized form increases ten-fold as a result of a rise in temperature and pH. The rise in pH from about 8 to 8.4 in the surface waters is believed to be caused by the removal of carbon dioxide from the water column as a result of algal photosynthesis.

By far the largest source of ammonia input to the Harbour was the Hamilton STP which discharged 5,300 kg/day in 1987, or about 70% of the total loading (Figure 17).

The Burlington STP represented the second largest source of ammonia being discharged to the Harbour, with a loading of 1150 kg/day in 1987, or about 15% of the total loading.

The third largest source of ammonia discharge in 1987 was Stelco with a loading of 627 kg/day in 1987. Stelco is nearing

Figure 15

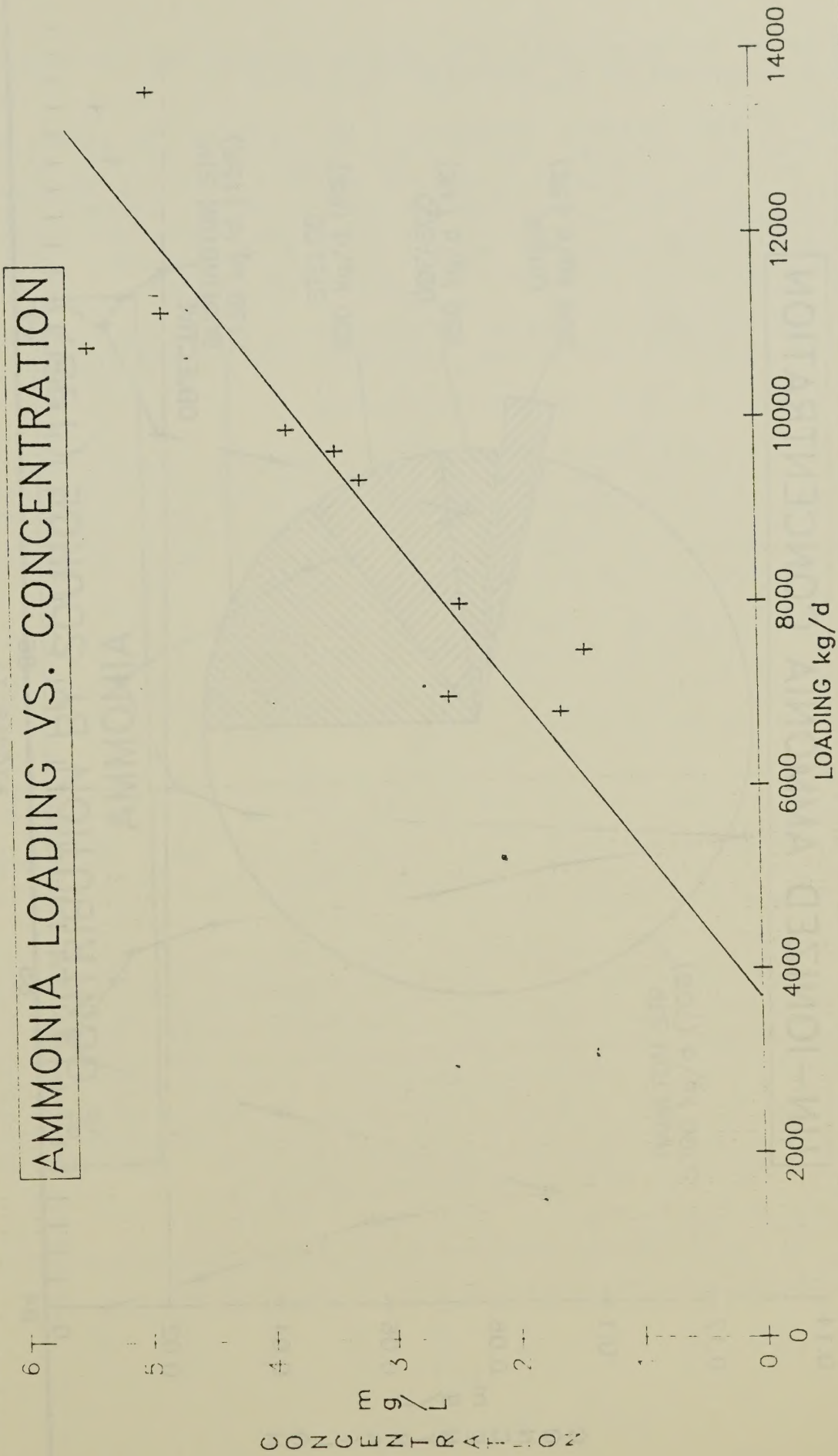


Figure 16

UN-IONIZED AMMONIA CONCENTRATION

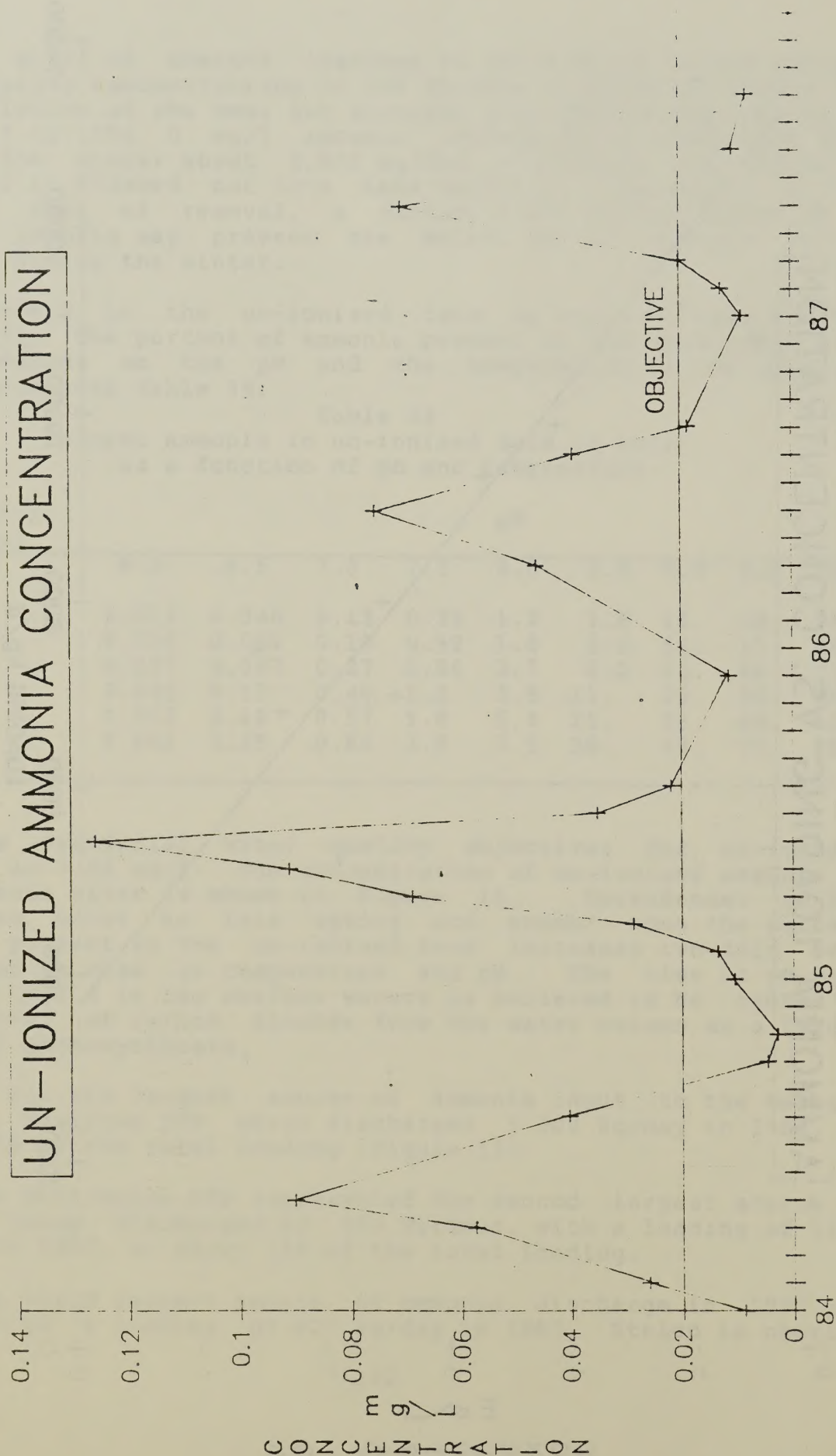
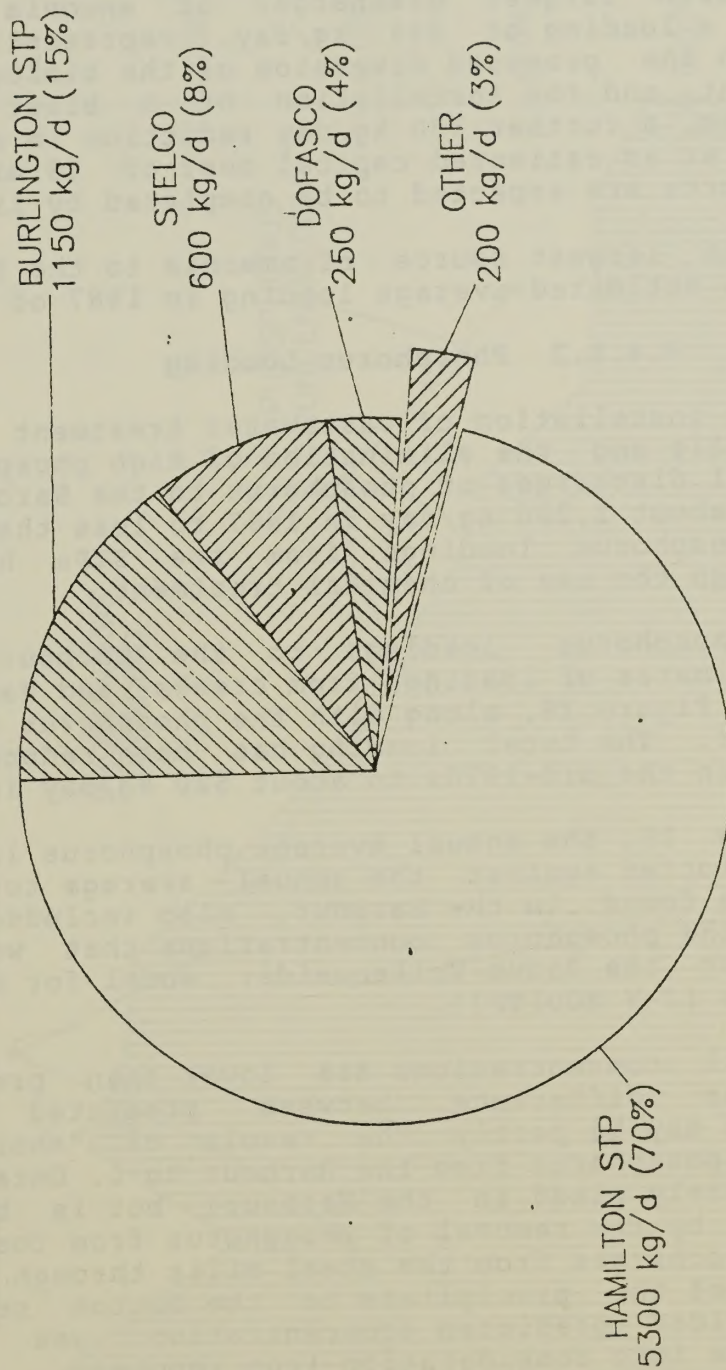


Figure 17

% CONTRIBUTION BY SOURCE (1987)
AMMONIA



TOTAL 1987 AMMONIA LOADING: 7500 kg/d

completion of its water pollution control program and the loading in 1988 is expected to be less than 150 kg/day.

The fourth largest discharger of ammonia in 1987, was Dofasco with a loading of 244 kg/day, representing 3% of the total. With the proposed diversion of the biological treatment plant effluent, and the installation of a blast furnace water recycle system, a further 130 kg/day reduction in ammonia loading is expected, at an estimated capital cost of \$9 million. These additional works are expected to be completed by 1989.

The fifth largest source of ammonia to the Harbour was the CSOs, with an estimated average loading in 1987 of 200 kg/day.

V.4.1.2 Phosphorus Loading

With the installation of wastewater treatment facilities at the steel mills and the elimination of high phosphorus sources, the industrial discharges of phosphorus to the Harbour have been reduced from about 1,200 kg/day in 1967 to less than 30 kg/day in 1987. The phosphorus loadings from the STPs have also been reduced through the use of chemical treatment.

Total phosphorus loadings to the Harbour since 1974, including estimates of loadings from creeks and Hamilton's CSOs, are shown in Figure 18, along with the phosphorus concentrations in the Harbour. The total loading has been reduced from about 1,500 kg/day in the mid-1970s to about 520 kg/day in 1987.

In Figure 19, the annual average phosphorus loadings to the Harbour are plotted against the annual average total phosphorus concentrations found in the Harbour. Also included in Figure 19 is a plot of the phosphorus concentrations that would have been predicted using the Janus-Vollenweider model for annual average concentrations (J-V MOD[TP]).

The actual concentrations are lower than predicted by the model. The difference between predicted and observed concentrations may be partly the result of "short circuiting" (flushing of phosphorus from the Harbour to L. Ontario before it becomes completely mixed in the Harbour) but is believed to be mainly caused by the removal of phosphorus from the water column by the iron discharges from the steel mills through precipitation and settling of the precipitate to the bottom sediments. The Janus-Vollenweider predicted concentration was modified as follows to take into consideration iron inputs:

$$P_c = 9.4 (I + 1400)^{-0.31} P_{j-v}$$

Where P_c is the predicted phosphorus concentration corrected for iron input.

I is the iron loading from the steel mills in kg/day.

Figure 18

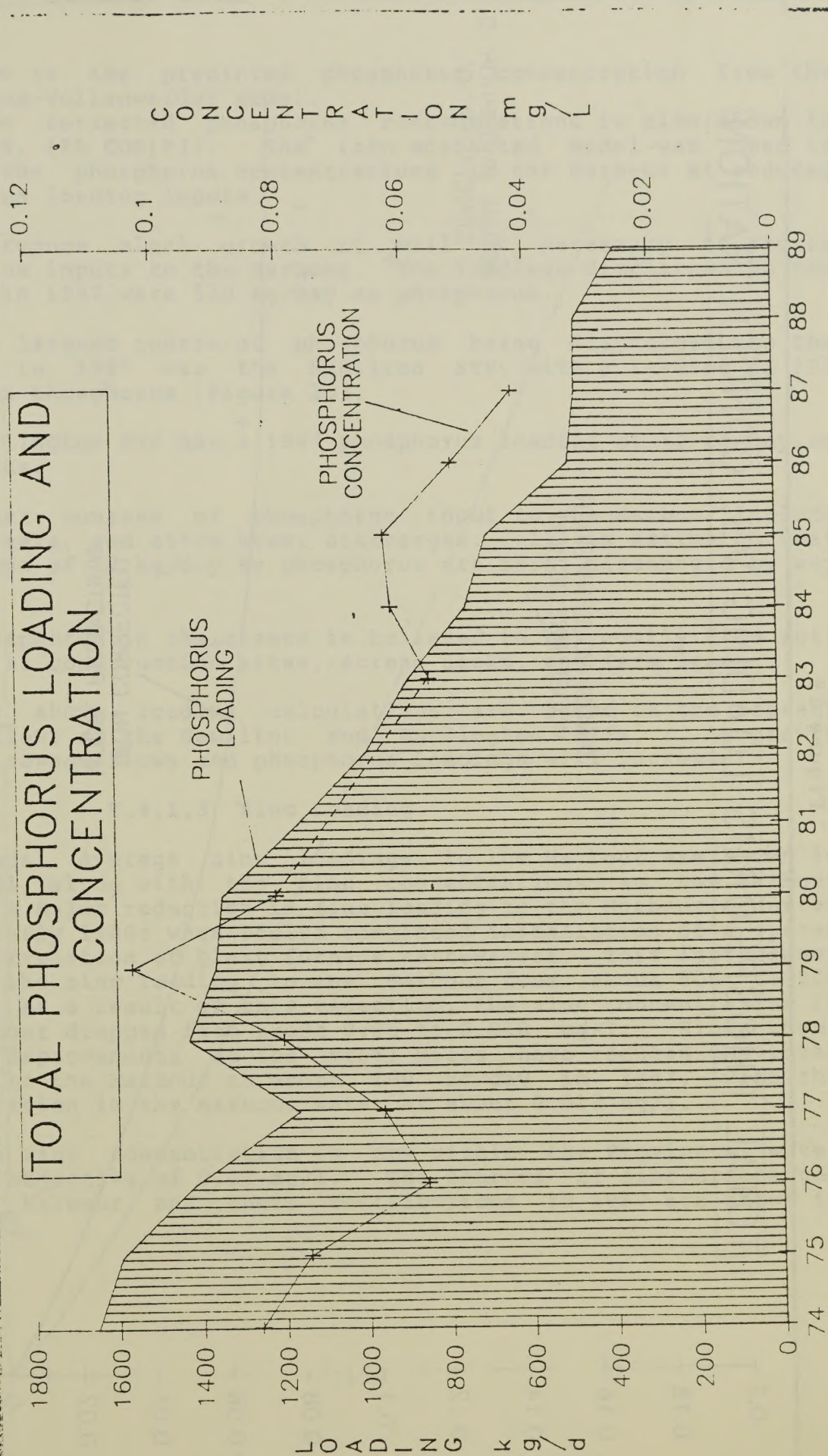
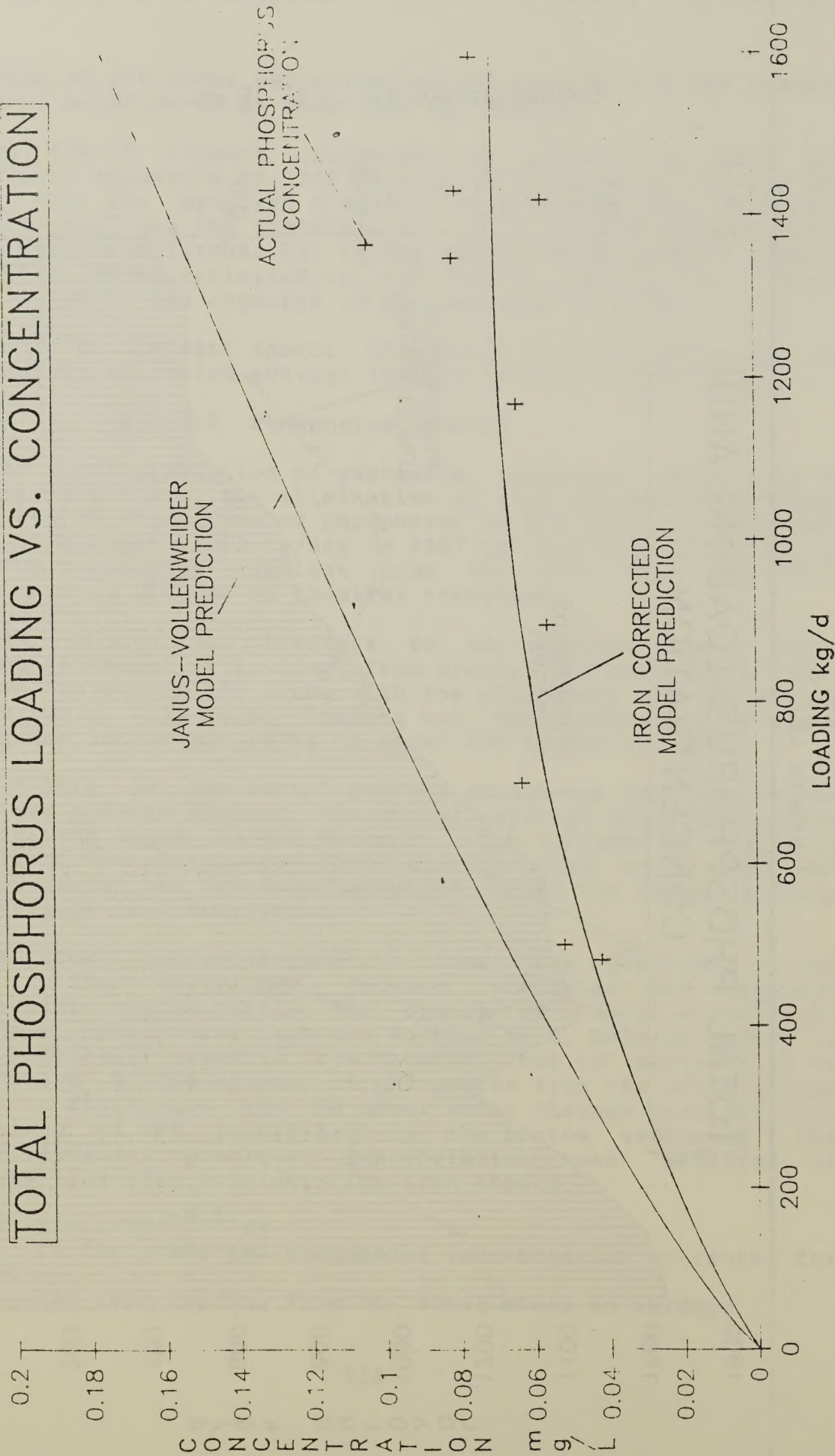


Figure 19

TOTAL PHOSPHORUS LOADING VS. CONCENTRATION



Pj-v is the predicted phosphorus concentration from the Janus-Vollenweider model.

The iron corrected phosphorus concentrations is also shown in Figure 19, (FE COR[P]). The iron corrected model was used to predict the phosphorus concentrations in the Harbour at reduced phosphorus loading inputs.

To reduce algal growth it will be necessary to reduce phosphorus inputs to the Harbour. The loadings discharged to the Harbour in 1987 were 520 kg/day as phosphorus.

The largest source of phosphorus being discharged to the Harbour in 1987 was the Hamilton STP, with a loading of 292 kg/day as phosphorus (Figure 20).

Burlington STP has a 1987 phosphorus loading of 42 kg/day as phosphorus.

Other sources of phosphorus input to the Harbour include CSOs, creeks, and storm sewer discharges. It is estimated that an average of 78 kg/day as phosphorus are being discharged by way of CSOs.

Phosphorus in the creeks is believed to be mostly from soil erosion at construction sites, stream banks, and farm land.

The above loading calculations are based on the present sewage flows at the Hamilton and Burlington STPs. As growth occurs, sewage flows and phosphorus loadings will increase.

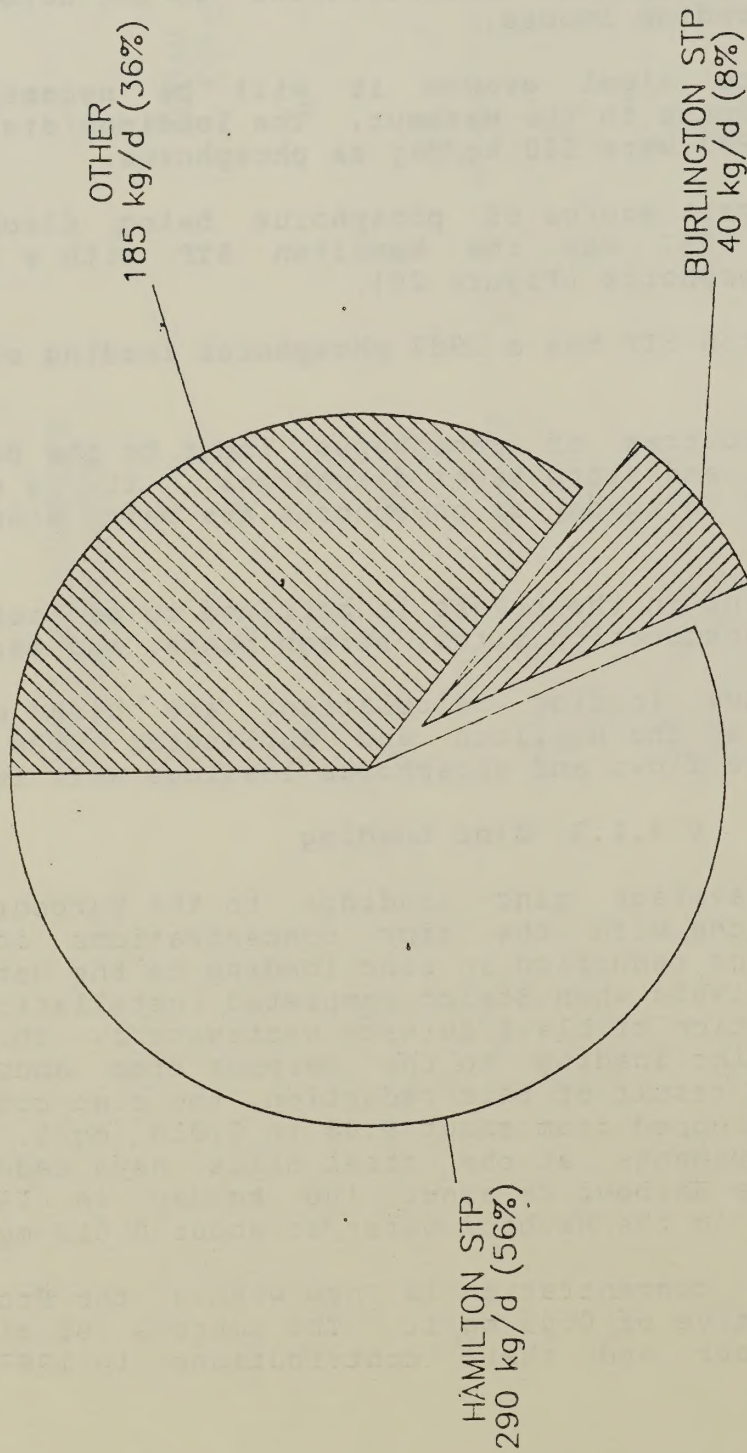
V.4.1.3 Zinc Loading

Annual average zinc loadings to the Harbour are shown in Figure 21, along with the zinc concentrations in the Harbour water. A major reduction in zinc loading to the Harbour occurred in the early 1980s when Stelco completed installation of a system for recirculation of blast furnace wastewaters. This improvement reduced the zinc loading to the Harbour from about 800 to 200 kg/day. As a result of this reduction, the zinc concentration in the Harbour dropped from about 0.05 to 0.018 mg/l. Since then, further improvements at the steel mills have reduced the total loading to the Harbour to about 100 kg/day in 1987, with the concentration in the Harbour water at about 0.013 mg/l.

The zinc concentration is now within the Provincial water quality objective of 0.03 mg/l. The sources of zinc discharged to the Harbour and their contributions in 1987 are shown in Figure 22.

Figure 20

% CONTRIBUTION BY SOURCE (1987)
TOTAL PHOSPHORUS



TOTAL 1987 TOTAL PHOSPHORUS LOADING: 515 kg/d

Figure 21

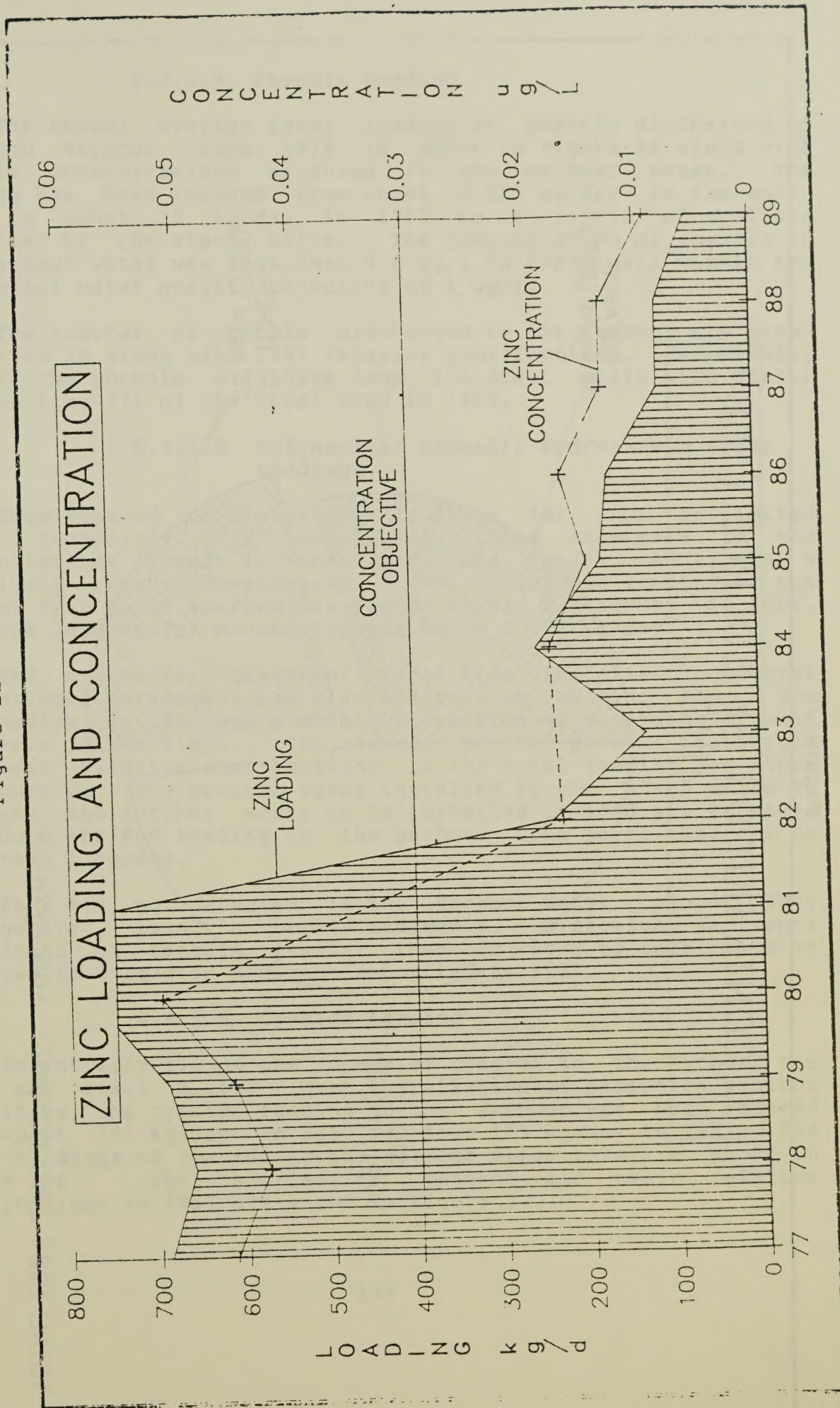
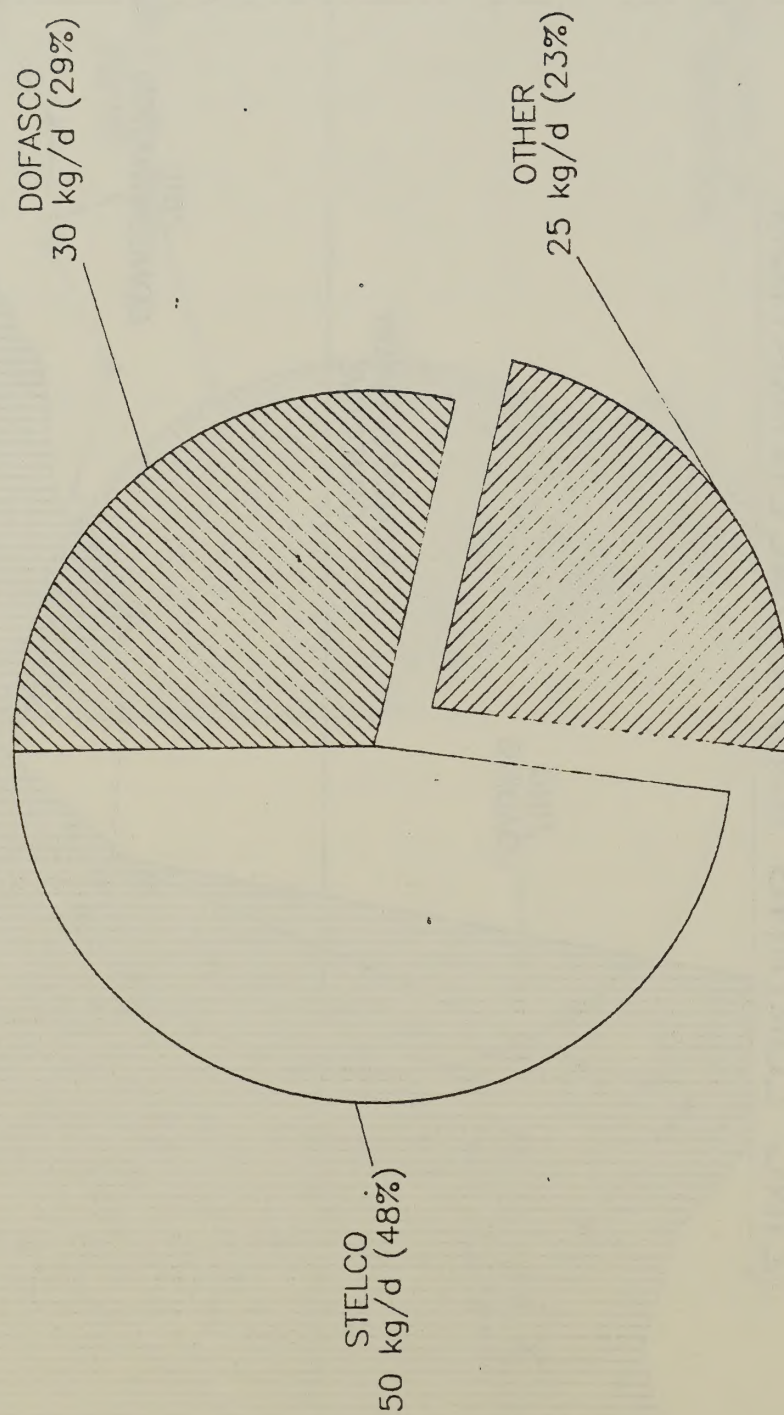


Figure 22

% CONTRIBUTION BY SOURCE (1987)
ZINC



TOTAL 1987 ZINC LOADING: 105 kg/d

V.4.1.4 Phenols Loading

The annual average total loading of phenols discharged to Hamilton Harbour since 1974 is shown in Figure 23 along with phenols concentrations measured in the Harbour water. The loading has been reduced from about 2,600 kg/day in the early 1970s to about 38 kg/day in 1987 as a result of controls installed by the steel mills. The concentration of phenols in the Harbour water was less than 0.4 ug/l in 1987, well within the Provincial water quality objective of 1 ug/l.

The sources of phenols discharged to the Harbour are shown in Figure 24 along with 1987 relative contributions. Essentially all of the phenols originate from the steel mills with Stelco representing 77% of the total load in 1987.

V.4.1.5 Polynuclear Aromatic Hydrocarbon (PAH) Loadings

Knowledge of the historical loadings for PAHs is limited since technology for monitoring these chemicals in the concentrations found in the effluents (ng/l range) is a relatively recent development. The total PAH loading to the Harbour from point sources was found to be 1.8 kg/day in 1986, with the loading for benzo(a)pyrene being 0.068 kg/day.

The wastewater treatment facilities installed to control conventional parameters are also efficiently removing PAHs. The PAH loading in 1987 was probably a fraction of a percent of what they were 20 years ago. The sources of the present discharges and their relative contributions to the total loading are shown in Figure 25. The control works installed by the steel mills in 1987 and the further works to be installed in 1988 are expected to reduce the PAH loading to the Harbour from point sources to less than 1 kg/day.

PAHs are not detected in the Harbour water column. They are, however, found in bottom sediments. Historical sediments are found to contain greater than 50 $\mu\text{g/g}$ of total PAHs as compared to 4 $\mu\text{g/g}$ in sediment deposited in 1987.

V.4.1.6 Cyanide Loading

Essentially all of the inputs of cyanide to the Harbour are from the steel mills. With installation of pollution control facilities, the cyanide loading to the Harbour has been reduced from about 700 kg/day in 1967 to about 185 kg/day in 1987. The total loadings of cyanide to the Harbour since 1974 are shown in Figure 26. The sources of cyanide and their relative contributions in 1987 are shown in Figure 27.

Figure 23

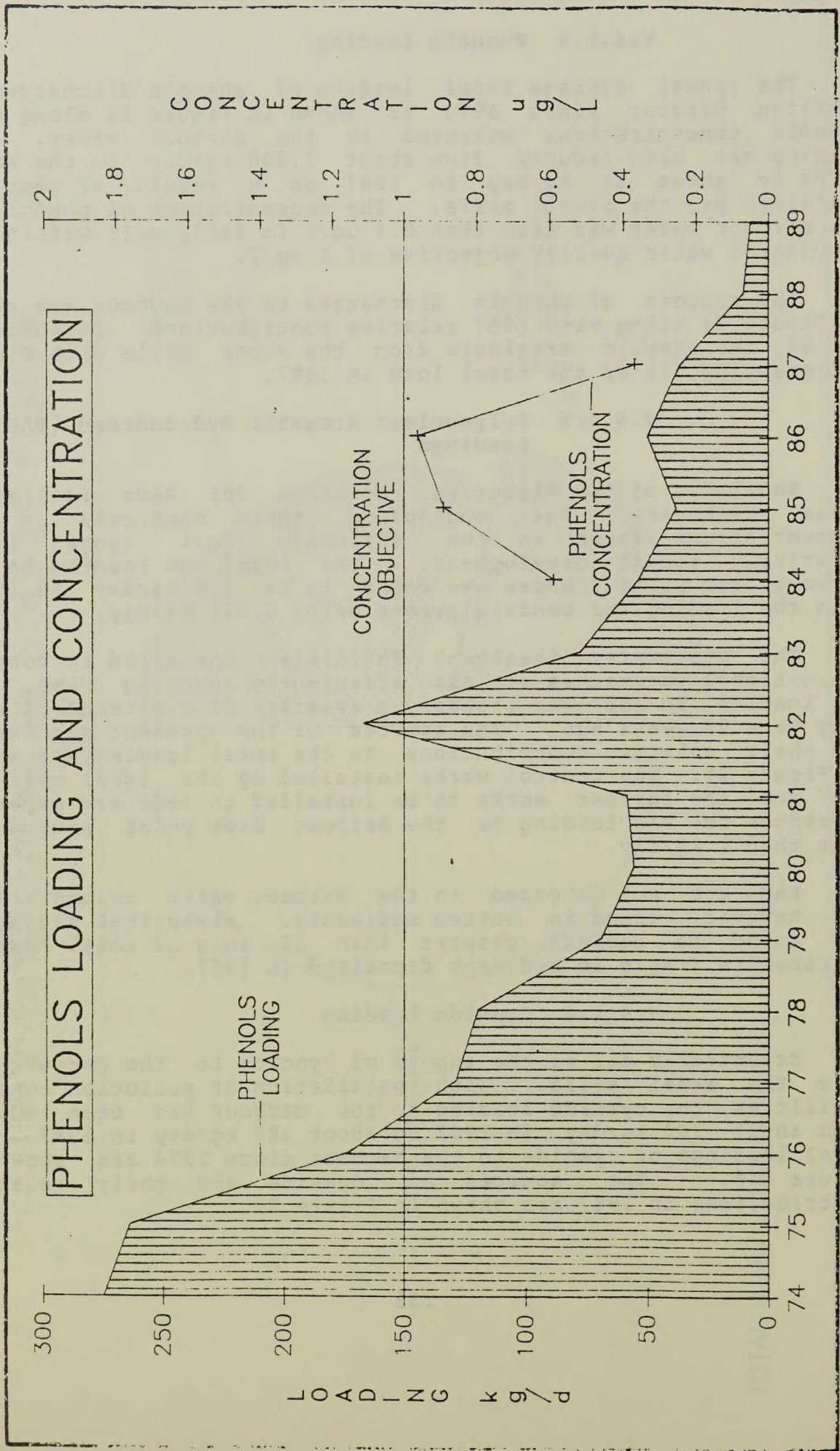
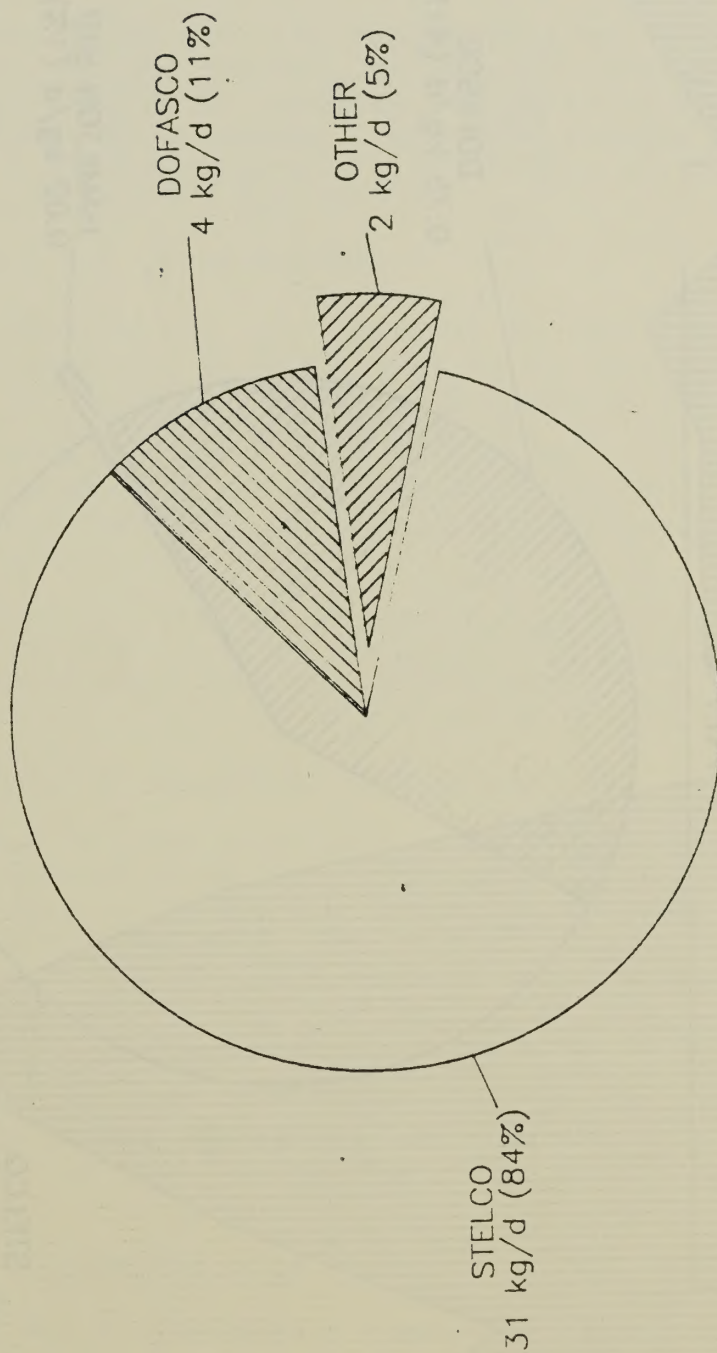


Figure 24

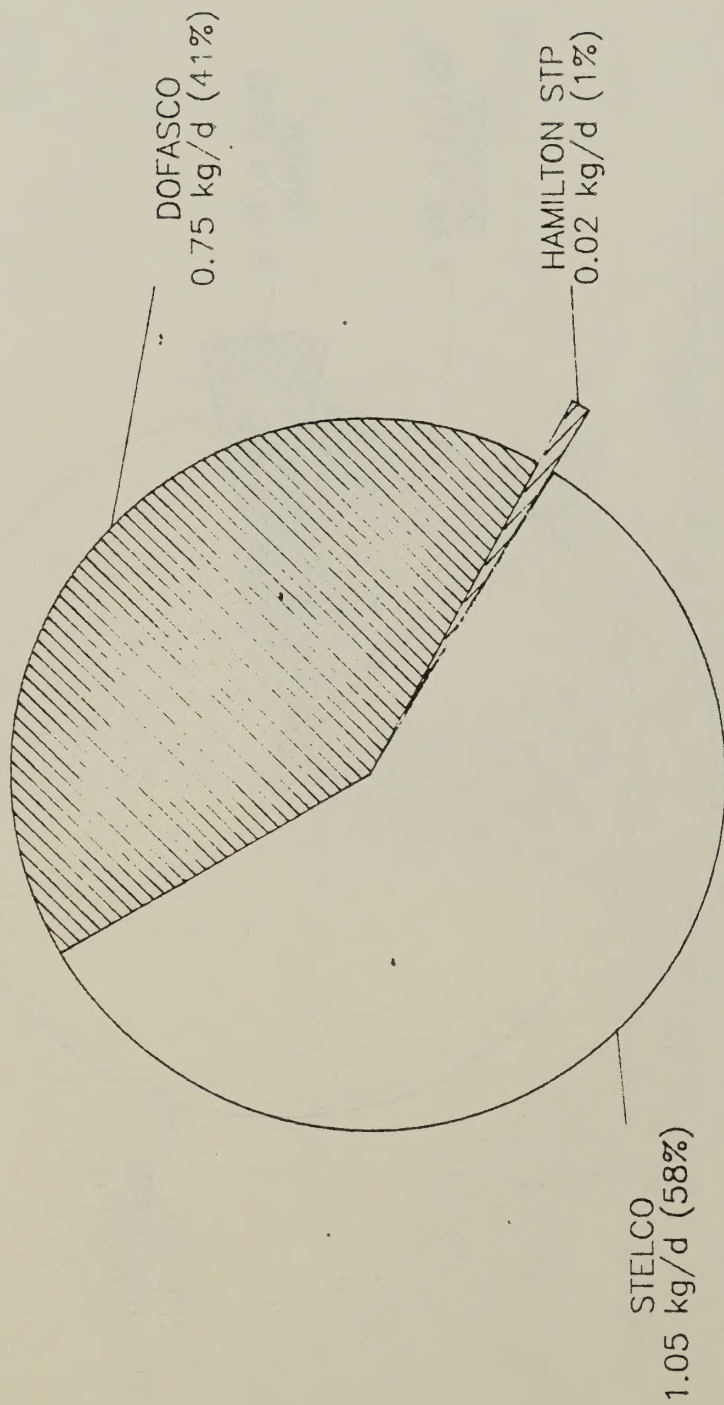
% CONTRIBUTION BY SOURCE (1987)
PHENOLS



TOTAL 1987 PHENOLS LOADING: 37 kg/d

Figure 25

% CONTRIBUTION BY SOURCE (1986)
PAH's



TOTAL 1986 PAH'S LOADING: 1.82 kg/d

Figure 26

CYANIDE LOADING

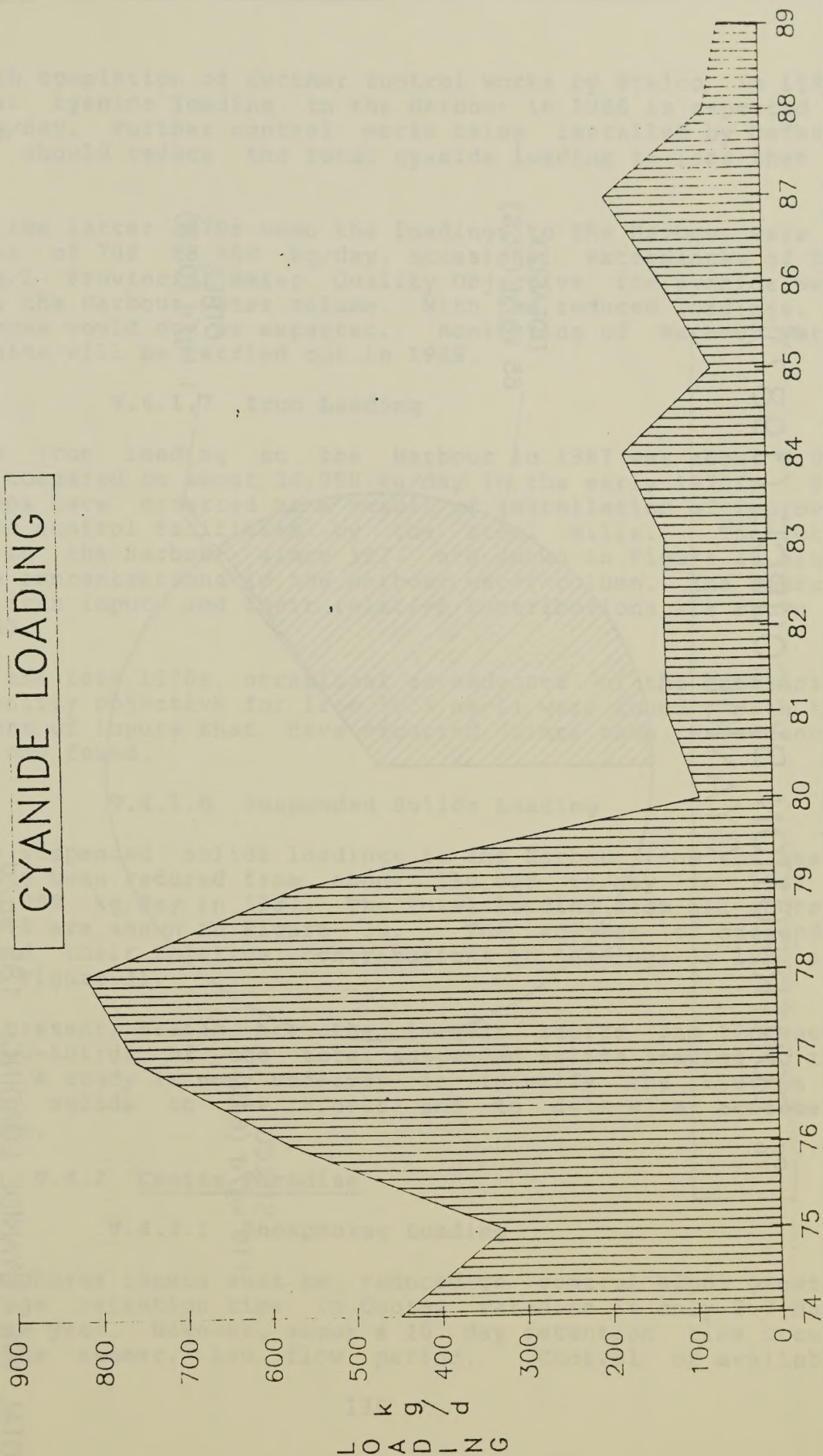
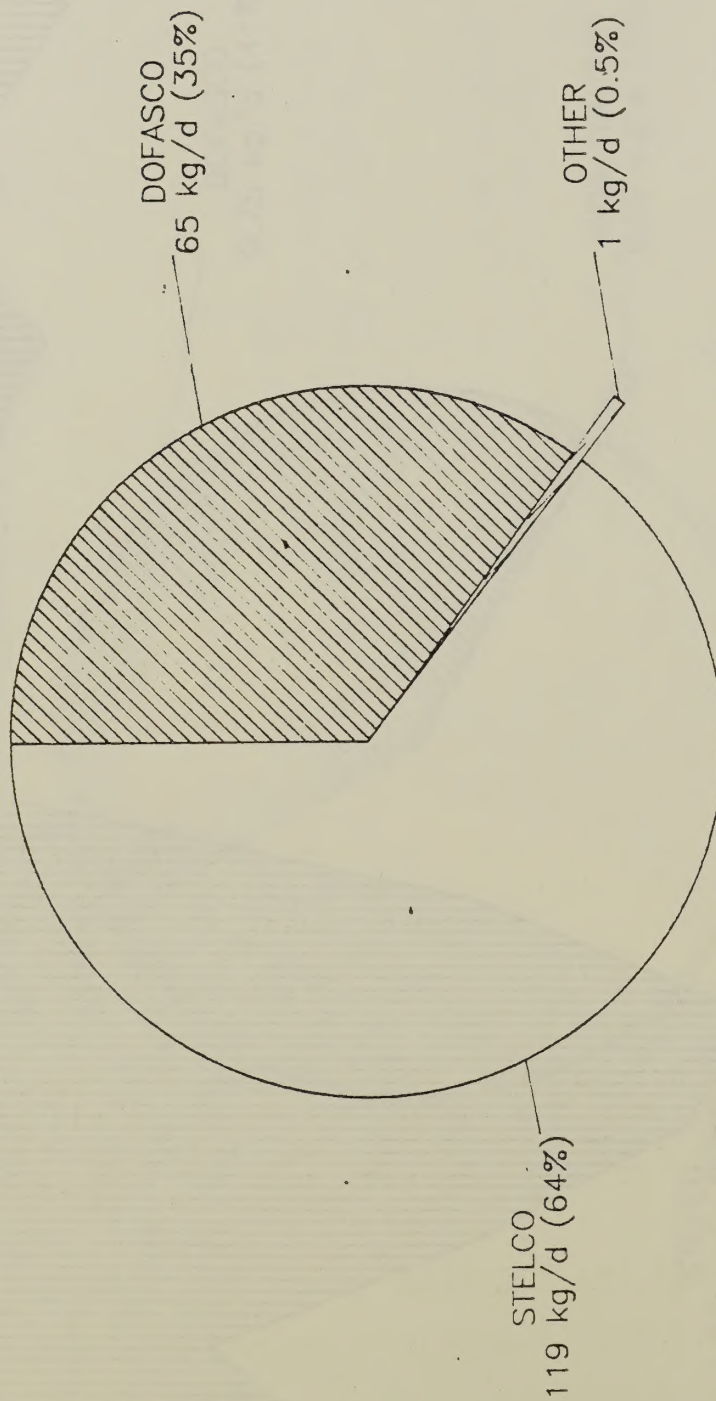


Figure 27

% CONTRIBUTION BY SOURCE (1987)
CYANIDE



TOTAL 1987 CYANIDE LOADING: 185 kg/d

With completion of further control works by Stelco in 1987, the total cyanide loading to the Harbour in 1988 is expected to be 70 kg/day. Further control works being installed by Dofasco in 1988 should reduce the total cyanide loading to less than 50 kg/day.

In the latter 1970s when the loadings to the Harbour were in the order of 700 to 800 kg/day, occasional exceedences of the 0.005 mg/l Provincial Water Quality Objective for cyanide were found in the Harbour water column. With the reduced loadings, no exceedences would now be expected. Monitoring of Harbour water for cyanide will be carried out in 1988.

V.4.1.7 Iron Loading

The iron loading to the Harbour in 1987 was about 4,000 kg/day, compared to about 20,000 kg/day in the early 1970s. The reductions have occurred as a result of installation of improved pollution control facilities by the steel mills. The total loading to the Harbour since 1974 are shown in Figure 28 along with the concentrations in the Harbour water column. The sources of the iron input and their relative contributions are shown in Figure 29.

In the late 1970s, occasional exceedences of the Provincial Water Quality Objective for iron (0.3 mg/l) were found. With the reductions of inputs that have occurred since then, exceedences are not now found.

V.4.1.8 Suspended Solids Loading

The suspended solids loadings to the Harbour from the steel mills have been reduced from about 150,000 kg/day in 1967 to about 12,000 kg/day in 1987. The total loading from all sources since 1978 are shown in Figure 30. The sources of suspended solids and their relative contributions to loadings in 1987 are shown in Figure 31.

At present, creeks are the largest source and represent about two-thirds of the total suspended solids loading to the Harbour. A study is now underway to identify the sources of suspended solids to the creeks and to determine abatement strategies.

V.4.2 Cootes Paradise

V.4.2.1 Phosphorus Loading

Phosphorus inputs must be reduced to control algal growth. The average retention time in Cootes Paradise is only 2.7 days during the year. However, about a 20 day retention time occurs during the summer, low flow period. Control of available

Figure 28

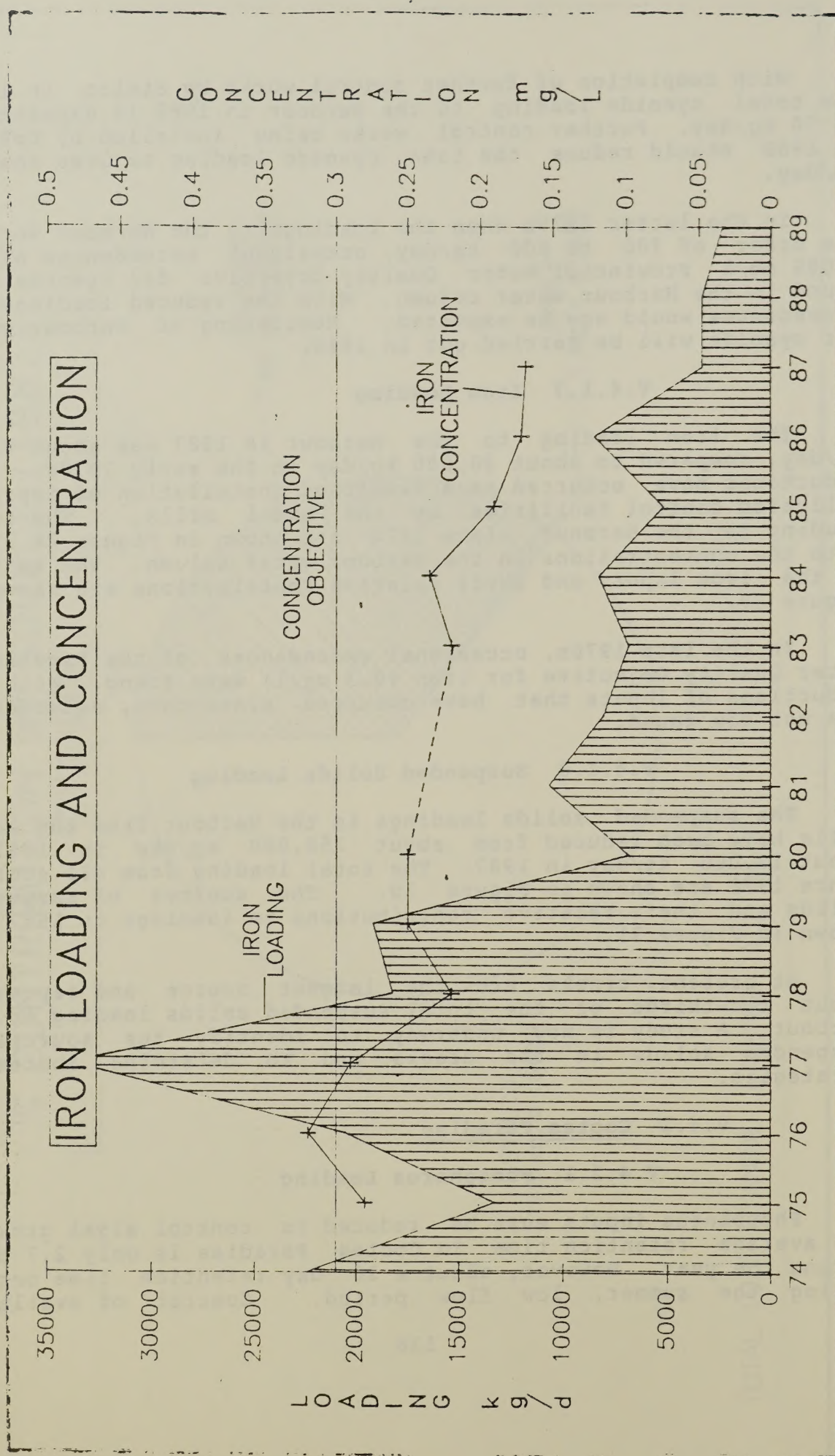
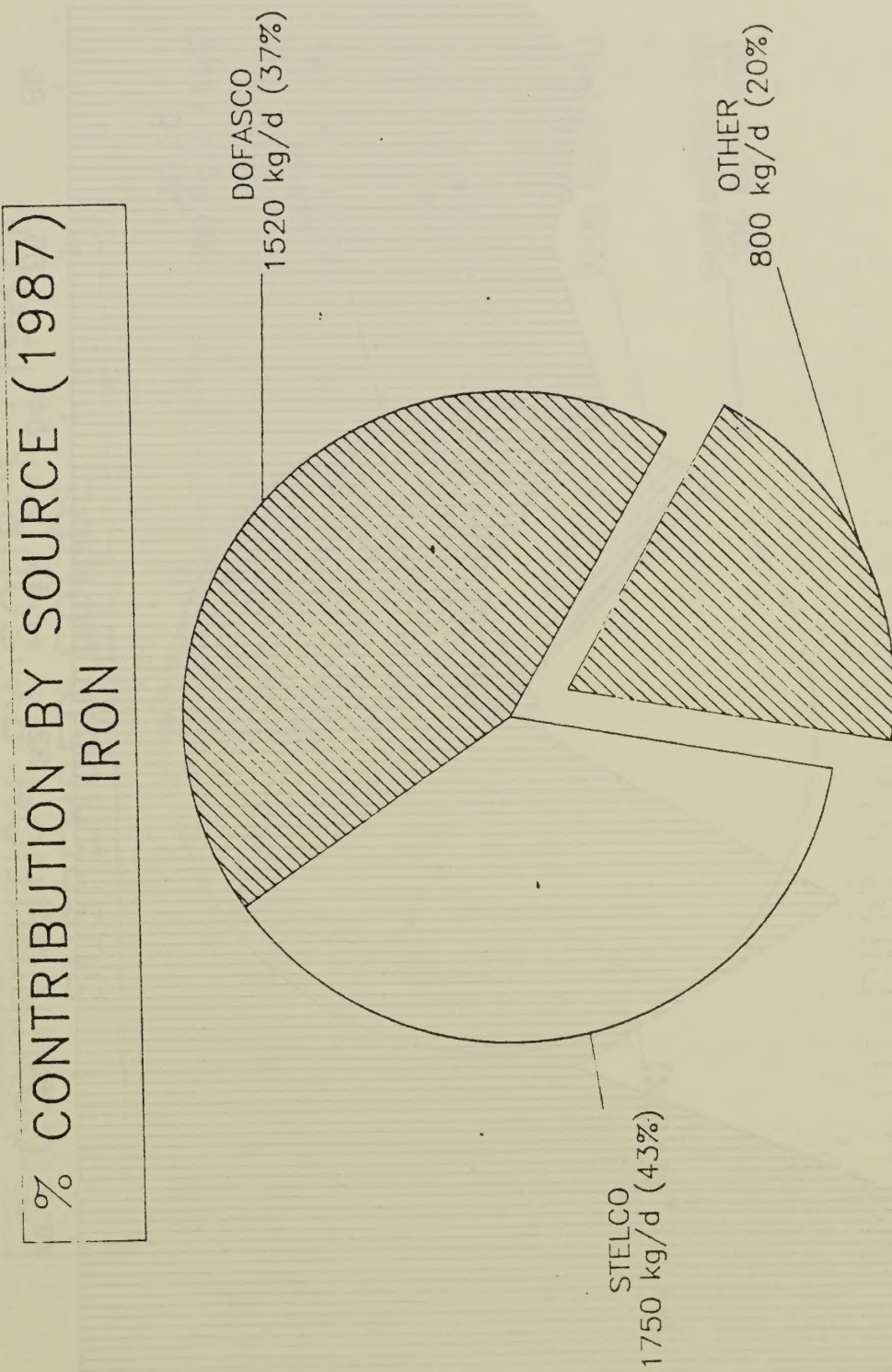


Figure 29



TOTAL 1987 IRON LOADING: 4070 kg/d

Figure 30

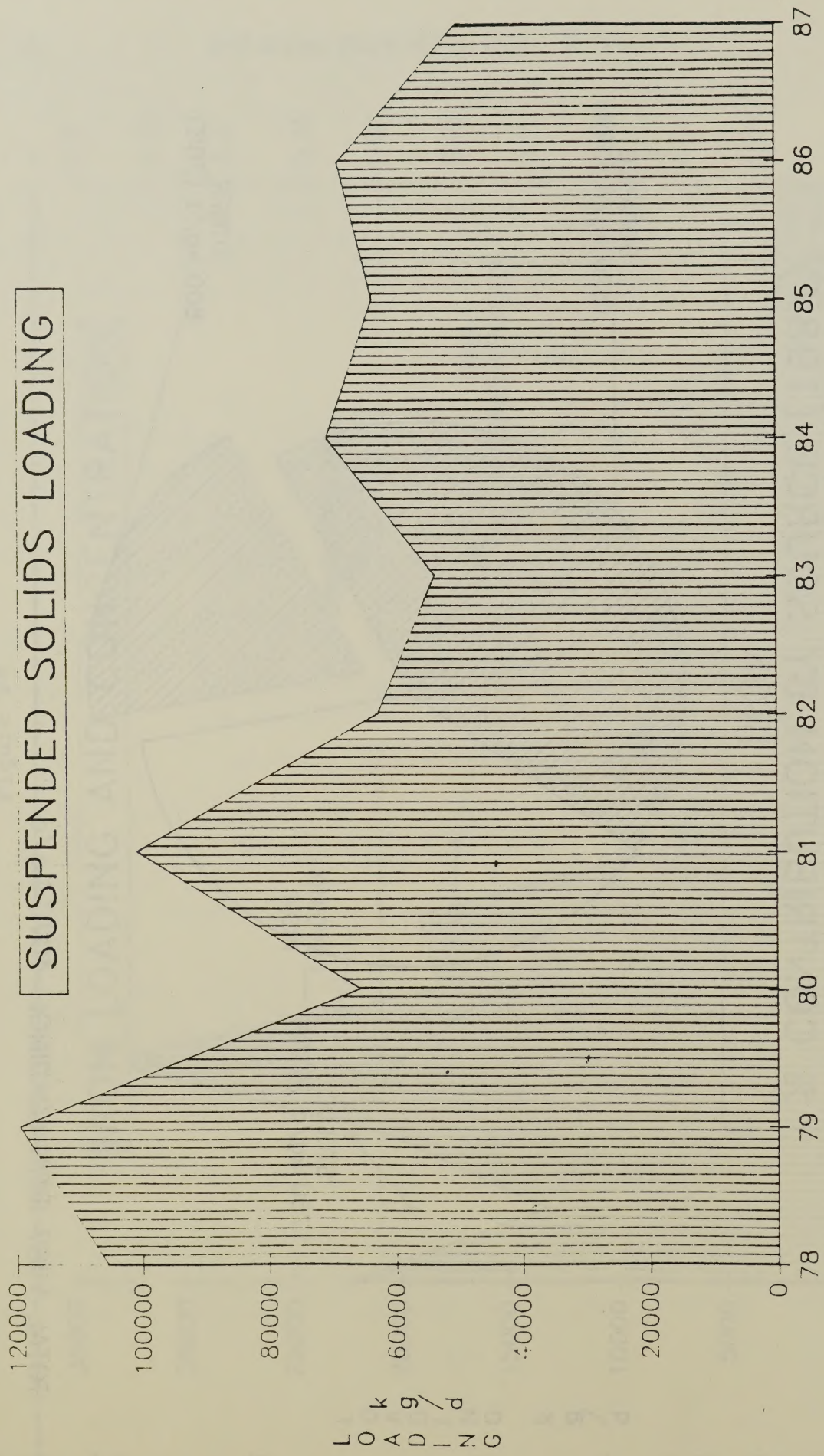
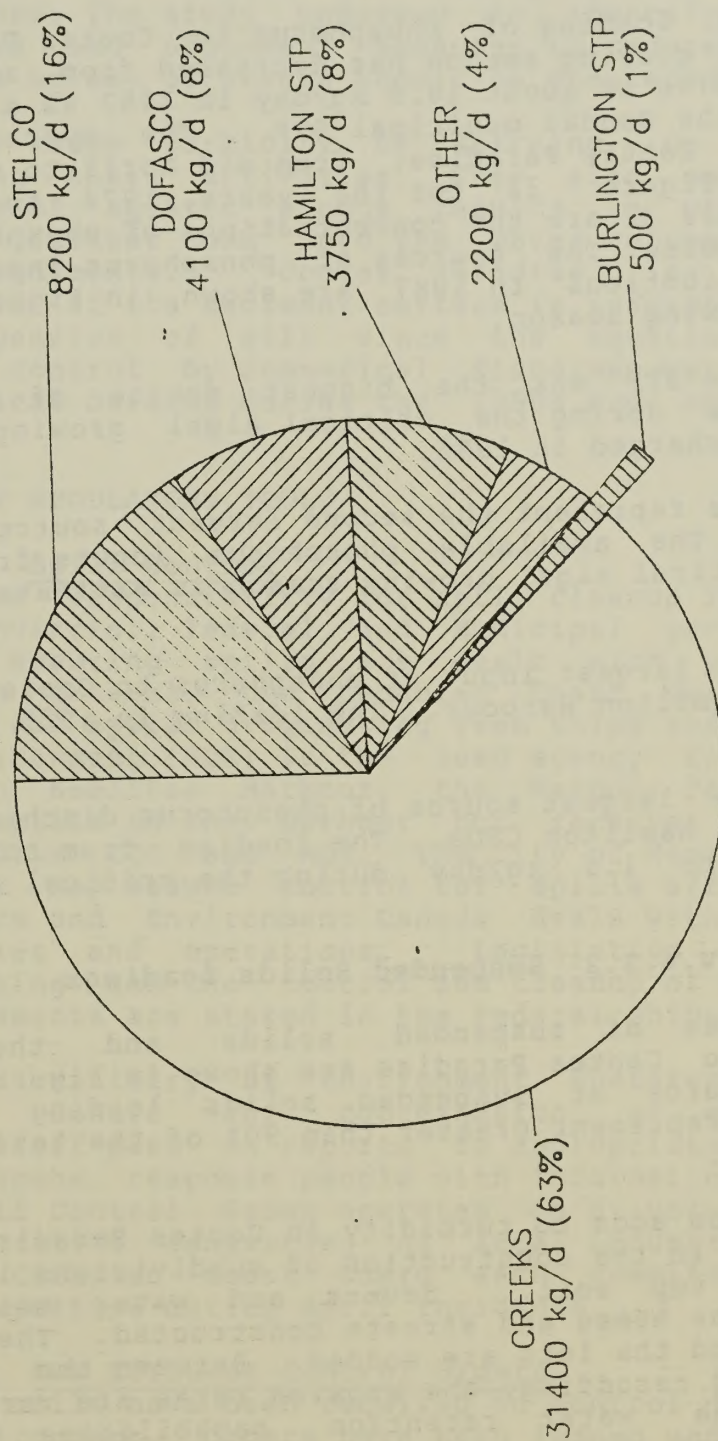


Figure 31

% CONTRIBUTION BY SOURCE (1987)
SUSPENDED SOLIDS



TOTAL 1987 SUSPENDED SOLIDS LOADING: 50150 kg/d

phosphorus inputs during the peak algal growing season of mid April to mid September is important.

The total loading of phosphorus to Cootes Paradise during the peak algal growing season has decreased from about 27 Kg/day in the mid 1970s to about 10.6 Kg/day in 1987 as a result of the expansion of the Dundas municipal STP. The average loadings of phosphorus to Cootes Paradise, from mid April to mid September, are shown in Figure 32 for the years, 1974 to present. Also shown in Figure 32 are the concentrations of phosphorus measured in Cootes Paradise. The sources of phosphorus inputs and their relative contributions in 1987 are shown in Figure 33 for the peak algal growing season.

The Dundas STP was the biggest source of phosphorus to Cootes Paradise during the critical algal growing season, with 7.3 kg/day discharged in 1985.

The creeks represent the second largest source of available phosphorus. The available phosphorus inputs from the creeks during the critical algal growing season is estimated to be about 3.4 kg/day.

The third largest input of phosphorus to Cootes Paradise is derived from Hamilton Harbour. The loading in 1985 was estimated to be 2 kg/day.

The fourth largest source of phosphorus discharge to Cootes Paradise is the Hamilton CSOs. The loading from this source is estimated to be 1.6 kg/day during the critical algal growing season.

V.4.2.2 Suspended Solids Loadings

The sources of suspended solids and their relative contributions to Cootes Paradise are shown in Figure 34. By far the largest source of suspended solids loading is from the creeks, which represent greater than 90% of the total loading to Cootes Paradise.

Soil erosion adds to turbidity in Cootes Paradise. The most common practice in the construction of subdivisions is to, first, strip off the top soil. Sewers and water mains are then installed and the homes and streets constructed. The top soil is then replaced and the lots are sodded. Between the stripping of the top soil and resodding, the erosion rates are very high. With development, the water retention capabilities are reduced resulting in more rapid runoff of precipitation. The more rapid runoff, in turn, causes higher peak stream flows which results in increased erosion of stream beds and banks. As well, the trend in the farming community has been towards the planting of more row crops such as corn. Soil is less protected from erosion with

these crops. Measures to control soil erosion include: settling basins for runoff from construction sites; storm retention basins to reduce peak storm flows; installing rip rap on creek beds and banks susceptible to erosion and modifying farm practices to minimize soil loss. The study underway to identify sources of suspended solids and abatement measures to reduce loadings of suspended solids by way of creeks should be completed in 1988.

Carp also cause turbidity by stirring up the bottom sediments during their activities. They also uproot aquatic plants. The loss of aquatic plants results in wind and wave energy reaching further down into the water column and perhaps reaching the sediments. Cootes Paradise is shallow and approximately 70% of its sediment surface is susceptible to wind and wave resuspension of silt since the aquatic plants are missing. Carp control by commercial fishermen was promoted by the Royal Botanical Gardens during the 1950s and aquatic plants returned.

V.5 CURRENT REGULATORY TOOLS

V.5.1 Spill Control

The ultimate responsibility for spill cleanup lies with the polluter but Provincial, Federal and Municipal governments are charged with ensuring spills are dealt with promptly and adequately. In general, the Canadian Coast Guard (CCG) is responsible for all spills originating from ships and the Ontario Ministry of Environment (MOE) is the lead agency for land based incidents. In Hamilton Harbour, the Harbour Commission has authority over spills in the Harbour but receives support for legal action from CCG and MOE. The City of Hamilton, Public Works department may assume control for spills affecting roads and storm sewers and Environment Canada deals with spills from federal facilities and operations. Legislation requires the immediate reporting and the control and cleanup of spills. The specific requirements are stated in the Federal Shipping Act.

The Ontario Ministry of Environment operates a 24 hour Spills Action Centre for coordination of environmental emergencies. Staff pass on reports to appropriate individuals and assist on scene response people with information. The Port of Hamilton Spill Control Group operates on a voluntary basis. It is a cooperative consisting of local industries, Harbour Commission and Canadian Coast Guard each committed to share equipment and expertise during spill incidents.

V.5.2 MOE Effluent Control Orders

The steel mills have been required to control discharges to the natural environment. Orders have been issued under Section 6 of the Ontario Environmental Protection Act requiring such controls. The last Orders were served upon the steel mills in

1980-81. The mills are complying with the Orders with the last items to be completed in June 1989.

V.5.3 Municipal/Industrial Strategy for Abatement (MISA)

The Municipal Industrial Strategy for Abatement is Ontario's new control program designed to systematically reduce the discharge of toxic contaminants.

The ultimate goal of the program is the virtual elimination of persistent toxic contaminants in municipal and industrial discharges to Provincial waterways. The program was announced in 1986 by Environment Minister Jim Bradley.

MISA is a regulatory program which will be implemented over a 3 year period. For each of the eight major sectors of industry and the municipal sector, two regulations will be developed. Initially, discharges will be subject to a monitoring regulation which will require them to identify and measure concentrations and amounts of conventional and toxic contaminants in their effluents. This information will be used to formulate Effluent Limits Regulations.

The MISA Program is being undertaken in full consultation with Environment Canada, municipalities, industries, interest groups and the general public. The MISA Advisory Committee is made up of independent technical and environmental experts. The purpose of the Advisory Committee is to review the draft regulations and provide advice and recommendations to the Environment Minister. Joint Technical Canada and affected industries, oversee studies and provide advice on the contents of monitoring and abatement regulations.

The two sectors of principal concern for Hamilton Harbour are the municipal sector, and the iron and steel sector. The schedules for the monitoring phase and the phase specifying the best available technology, economically achievable (BATEA) are described below.

In the Iron and Steel industry, work began on the pre-regulation monitoring program in April 1987 and the first sampling run was completed in November. The results will be discussed at the upcoming IJC meeting.

In the municipal sector, a regulation writing team will be formed early in 1988. Public release of a draft monitoring regulation for the municipal sector is expected before the end of the year.

Monitoring of STP's have been designed to cover periods when chlorination is and is not being used.

The Iron and Steel Sector participants are monitoring specific water supply and waste streams.

In Hamilton, DOFASCO is monitoring:

1. Biological Treatment Plant Influent
2. Biological Treatment Plant Effluent
3. Basic Oxygen Furnace slurry line
4. Hot Rolling Filter Plant location
5. Water Supply Intake

and STELCO is monitoring:

1. Hilton Works - Water Intake #1
2. Hilton Works - Water Intake #2
3. Filter Plant Outlet
4. Blast Furnace Blowdown location
5. Oil Treatment Plant Effluent
6. Weak Ammonia Liquor (directed to Hamilton STP).

Both STELCO and DOFASCO are doing additional sampling at other locations as well.

The above documented work and schedules are based on the BAT "track" for the MISA program. If the receiving water conditions call for more stringent controls, they will be addressed in the third phase of the MISA program.

Work reported in this RAP, or the results of investigations recommended in this RAP, will form the basis for any controls beyond the best available technology, economically achievable.

V.5.4 Air Emission Controls

Control orders under Section 6 of the Ontario Protection Act have been issued to industries requiring reductions of emissions to air. As a result, industrial air emissions have been reduced by about 86% since 1970. Programs to control point source emissions will be completed in June 1989.

Efforts to reduce wind blown dust were started in the mid 1970s. As a result extensive controls have been placed on the coal fields and major roads within the steel mills have been paved and are being frequently cleaned. As well, landscaping to reduce wind blown dust has been proceeding since the late 1970s. As part of this program, landscaping is being installed around the perimeter of the properties adjacent to the Harbour. This landscaping will not only reduce wind blown dust but will also improve the appearance of the mill sites.

VI ANALYSIS OF OPTIONS

VI.1 INTRODUCTION

In the 1970s, measures were taken to repair the Harbour's condition and in the 15 years that followed, major improvements have occurred.

- * waterbirds have returned to the Harbour;
- * provincial water quality objectives for the protection of aquatic life have been met, except for ammonia and oxygen concentrations;
- * fish-eating birds are no longer experiencing breeding failures and deformities in their young;
- * there are signs that the number and diversity of fish species are increasing;
- * improvements have been documented in the number and type of aquatic worms inhabiting the Harbour's "bottom mud";
- * 42 species of fish are successfully reproducing in the Harbour;
- * there are seven out of 12 fish species in the Harbour which do not have fish consumption guideline restrictions.

These improvements are the result of the \$300 million that has been spent by industries and municipal governments to meet the water quality standards established by the IJC and the Ministry of the Environment.

While significant improvements have been made to the Harbour's water quality, a number of remaining problems still must be resolved:

- * waterfowl habitat in the Harbour has been lost;
- * there have been isolated incidents of lead contamination and botulism among water fowl;
- * colonial waterbird habitat will be lost due to development;
- * ammonia concentrations in the Harbour exceed the Great Lakes Water Quality objectives;
- * for two months in the summer, fish do not inhabit the deeper waters of the Harbour because oxygen concentrations are too low. These concentrations do not meet the Great Lakes Water Quality objectives;
- * there are fish consumption guideline restrictions for larger specimens of five species in the Harbour;
- * water clarity is restricting the potential of shallow water areas to become fish habitats by hindering aquatic plant growth;
- * water turbidity and possibly bacteria levels are too high to permit swimming.

The Stakeholders identified a series of enhanced and future use goals which have been described in the Interim Report of the Stakeholders (1986). The three key use goals are entitled Fisheries, Wildlife, and Swimming. Meeting these three goals will meet the requirements for the remaining goals.

The purpose of this chapter is the following:

1. a) to describe past improvements in water quality due to loading reductions
- b) to describe completed or nearly completed loading reductions and anticipated water quality improvements
- c) to describe options to improve water quality to comply with IJC and Provincial Water Quality

Objectives

2. to describe options for the attainment of the Stakeholders enhanced and future uses

The chapter is organized in two sections. The first section deals with three aspects of water quality outlined above and is titled; Overview of Loading Reductions. The second section describes remedial options to achieve the Stakeholders' goals.

VI.2 OVERVIEW OF LOADING REDUCTIONS: HAMILTON HARBOUR

VI.2.1 Ammonia Loading

VI.2.1.1 Historical Actions

Major reductions in industrial discharges of ammonia have been achieved. The industrial loadings have been reduced from about 24,000 kg/day of ammonia as nitrogen in 1967 to about 857 kg/day in 1987. However, there has been little change in the loadings of ammonia from the municipal STPs. Regular monitoring for ammonia in the effluents from the STPs was started in 1978.

Figure 14 shows the total loadings of ammonia as nitrogen from both industrial and municipal sources since 1978, including estimates of loadings in Hamilton's CSOs, and the concentration of ammonia found in the Harbour. The concentration trend in the Harbour is cyclical with the highest concentration occurring in the early spring and the lowest in the summer. The cyclical pattern is caused by the inhibition of cold temperatures on nitrifying bacteria which oxidize ammonia. As a result, the concentrations build up in the Harbour during the winter. In 1987, the concentration peaked at 1.5 mg/l. When the water temperature warms above 6 C in spring, the nitrifying bacteria become active again and very rapidly oxidize the accumulated ammonia. In so doing, the oxygen level in the Harbour water is reduced. The oxidation of each mg/l of ammonia, as nitrogen, requires about 4.6 mg/l of oxygen.

Not all of the ammonia discharged to the Harbour is oxidized. Ammonia is also flushed to the lake through the canal.

As well, some ammonia is used by the aquatic biota as a nutrient. It is initially taken up by aquatic plants, including algae, and by bacteria. A small portion of this nitrogen makes its way through the food chain, ending up as protein in fish and in water fowl.

A plot of ammonia loadings to the Harbour versus maximum early spring concentrations in the Harbour is shown in Figure 15. Extrapolation of the best fit straight line through the points in the plot to the 0 mg/l ammonia concentration indicates that during the winter about 3,600 kg/day of ammonia is utilized by algae or is flushed out into Lake Ontario. Therefore, at the present rate of removal, a further 4,200 kg/day reduction in ammonia loading may prevent the build up of ammonia in the Harbour during the winter.

Ammonia in the un-ionized form is toxic to some aquatic organisms. The percent of ammonia present in the un-ionized form is dependent on the pH and the temperature of the water in accordance with Table 34.

The Provincial water quality objective for un-ionized ammonia is 0.02 mg/l. The concentration of un-ionized ammonia in the Harbour water is shown in Figure 16. Exceedences of the objective occur in late spring and summer when the percent ammonia present in the un-ionized form increases ten-fold as a result of a rise in temperature and pH. The rise in pH from about 8 to 8.4 in the surface waters is believed to be caused by the removal of carbon dioxide from the water column as a result of algal photosynthesis.

VI.2.1.2 Current and Proposed Actions

The sources of ammonia to the Harbour include the Hamilton and Burlington STPs, the CSOs in Hamilton and the two integrated steel mills. The relative contribution of each source in 1987 is shown in Figure 17.

By far the largest source of ammonia input to the Harbour is the Hamilton municipal STP which discharged 5,300 kg/day in 1987, or about 70% of the total loading. The total Kjeldahl nitrogen (ammonia plus organic nitrogen) removal efficiency in the plant was about 40% in 1987. The efficiency of removal in the STP can be improved by increasing the sludge age. The nitrifying bacteria which oxidize ammonia are slow growers and therefore require a reduction in the wasting rate of the activated sludge to maintain a suitable biomass nitrifying bacteria. This can be achieved by increasing the activated sludge concentration in the aeration basin and/or the hydraulic capacity of the STP aeration basin.

The Hamilton municipal STP has spare aeration basin capacity. Thus, increasing the total Kjeldahl nitrogen removal

efficiency should be possible with minimal capital expenditure. Large scale pilot studies are being carried out at the plant to determine the maximum removal efficiency that can be attained without affecting the removal efficiency of suspended solids, BOD and phosphorus. These studies should be completed in 1988.

The Burlington municipal STP represents the second largest source of ammonia being discharged to the Harbour, with a loading of 1,150 kg/day in 1987, or about 15% of the total loading. As with the Hamilton STP, the efficiency of ammonia removal can be improved by increasing the sludge age through operating with a higher mixed liquor suspended solids concentration and/or increasing the hydraulic capacity of the aeration basin. The Regional Municipality of Halton is upgrading the municipal STP including changes to enhance ammonia removal. As well, a consultant is being retained to audit the plant to optimize its operation.

The ammonia in the municipal STP effluents will probably have to be reduced to 3000 kg/day or about 7.5 mg/l at present sewage flows to prevent build-up of ammonia in the Harbour during the winter and to prevent exceedence of the un-ionized ammonia objective in late spring and summer.

The third largest source of ammonia discharged in 1987 was Stelco, with an average loading of 627 kg/day or about 8% of the total loading. Stelco completed installation of indirect final coolers in 1987. As a result, the loading in 1988 is expected to be less than 150 kg/day.

The fourth largest discharger of ammonia in 1987, was Dofasco with a loading of 244 kg/day, representing 3% of the total. With the proposed diversion of the biological treatment plant effluent and the installation of a blast furnace water recycle system, the ammonia loading for Dofasco is expected to be reduced to about 120 kg/day, at an estimated capital cost of \$9 million. These additional works are expected to be completed by 1989.

The fifth largest source of ammonia to the Harbour is CSOs with an estimated average loading in 1987 of 200 kg/day. There are 26 CSOs in Hamilton. The Regional Municipality of Hamilton-Wentworth is installing a retention basin at one of the larger sewers to collect the overflow for pumping back into the sewer system for treatment after storm occurrences. Construction of the facility has been completed at a cost of \$6.3 million and is expected to be placed in operation in 1988. The cost of installing storage basins to control all CSOs is estimated to be about \$60 million. The construction of the retention basins could be completed in 5 years but current plans are for completion over a 20 - 40 year period. The Regional Municipality is also proposing to develop a computerized system to optimize

the storage capacity of the existing sewers. Such a system may reduce the overall cost of controlling CSOs.

VI.2.2 Phosphorus Loading

VI.2.2.1 Historical Actions

With the installation of wastewater treatment facilities at the steel mills and the elimination of high phosphorus sources, the industrial discharges of phosphorus to the Harbour have been reduced from about 1,200 kg/day in 1967 to less than 30 kg/day in 1987. The phosphorus loadings from the STPs have also been reduced through the use of chemical treatment.

Total phosphorus loadings to the Harbour since 1974, including estimates of loadings from creeks and Hamilton's CSOs, are shown in Figure 18, along with the phosphorus concentrations in the Harbour. The total loading has been reduced from about 1,500 kg/day in the mid-1970s to about 520 kg/day in 1987.

In Figure 19, the annual average phosphorus loadings to the Harbour are plotted against the annual average total phosphorus concentrations found in the Harbour. Also included in Figure 19 is a plot of the phosphorus concentrations that would have been predicted using the Janus-Vollenweider model for annual average concentrations (J-V MOD[TP]).

The actual concentrations are lower than predicted by the model. The difference between predicted and observed concentrations may be partly the result of "short circuiting" (flushing of phosphorus from the Harbour to L. Ontario before it becomes completely mixed in the Harbour) but is believed to be mainly caused by the removal of phosphorus from the water column by the iron discharges from the steel mills through precipitation and settling of the precipitate to the bottom sediments. The Janus-Vollenweider predicted concentration was modified as follows to take into consideration iron inputs:

$$P_c = 9.4 (I + 1400)^{-0.31} P_{j-v}$$

Where P_c is the predicted phosphorus concentration corrected for iron input.

I is the iron loading from the steel mills in kg/day.

P_{j-v} is the predicted phosphorus concentration from the Janus-Vollenweider model.

The iron corrected phosphorus concentrations is also shown in Figure 19, (FE COR[P]). The iron corrected model was used to predict the phosphorus concentrations in the Harbour at reduced phosphorus loading inputs.

VI.2.2.2 Current and Proposed Actions

The sources of phosphorus being discharged to the Harbour and their relative contributions in 1987 are shown in Figure 20. The annual average total loading to the Harbour in 1987 was 520 kg/day as phosphorus.

The largest source of phosphorus being discharged to the Harbour in 1987 was the Hamilton municipal STP with a loading of 292 kg/day or 56% of the total loading. Large scale studies are being carried out at the Hamilton plant to optimize the treatment for removal of phosphorus. It is believed that with such optimization, the effluent concentrations from the existing plant can be reduced to 0.5 mg/l, and possibly lower, as compared to an average concentration in 1987 of 0.9 mg/l. It is believed that similar reductions may also be achieved by optimizing the operation of the Burlington municipal STP which discharged 42 kg/day or 8% of the total in 1987.

Other sources of phosphorus input to the Harbour include CSOs, creeks, and storm sewer discharges. It is estimated that an average of 78 kg/day of phosphorus are being discharged by way of CSOs. The provision of sewage storage facilities, at all 26 CSOs as described earlier, should reduce the phosphorus loading from this source to about 5 kg/day as phosphorus.

Phosphorus in the creeks is believed to be mostly from soil erosion at construction sites, along stream banks, and of farm land. It is possible that reduction of erosion through more stringent controls at construction sites, installation of retention devices to minimize peak stream flows and/or structures to protect stream banks, and changing farm practices could reduce the phosphorus input from these sources by one-half. More field work is needed to determine the significance of each of these sources before an estimate can be made of the actual reduction attainable and its cost. This additional field work will be undertaken in 1988.

With reductions of the phosphorus concentrations in municipal STP effluents to 0.5 mg/l, elimination of CSOs in Hamilton and reduction of non-point sources by 50%, the total phosphorus loading to the Harbour would be reduced to about 240 kg/day. From Figure 19, the phosphorus concentration in the Harbour at a loading of 240 kg/day would be about 0.028 mg/l. If the concentrations in the municipal STP effluents can be reduced to 0.4 mg/l, the total loading to Harbour would be reduced to 200 kg/day and the concentrations in the Harbour water to about 0.023 mg/l.

VI.2.2.3 Future Actions

If the phosphorus loading to the Harbour cannot be reduced adequately by optimizing chemical treatment in the existing STPs, then an option would be to install filters to further treat the final effluent. The cost of a filtration system for the Hamilton municipal STP would be about \$40 million and for the Burlington municipal STP would be about \$15 million. With filtration and using dual point chemical addition, the phosphorus concentration

in the municipal STP effluents can be reduced to as low as 0.1 mg/l.

VI.2.3 Zinc Loading

VI.2.3.1 Historical Actions

Annual average zinc loadings to the Harbour are shown in Figure 21, along with the zinc concentrations in the Harbour water. A major reduction in zinc loading to the Harbour occurred in the early 1980s when Stelco completed installation of a system for recirculation of blast furnace wastewaters. This improvement reduced the zinc loading to the Harbour from about 800 to 200 kg/day. As a result of this reduction, the zinc concentration in the Harbour dropped from about 0.05 to 0.018 mg/l. Since then, further improvements at the steel mills have reduced the total loading to the Harbour to about 100 kg/day in 1987, with the concentration in the Harbour water at about 0.013 mg/l.

VI.2.3.2 Current Actions

The zinc concentration is now within the Provincial water quality objective of 0.03 mg/l. The sources of zinc discharged to the Harbour and their contributions in 1987 are shown in Figure 22.

Dofasco is now installing blast furnace wastewater recirculation with completion scheduled for the end of 1988. As well, Stelco will be making improvements to minimize equipment breakdowns. With these changes, the loading from Dofasco should be reduced to 19 kg/day and the loading from Stelco to about 30 kg/day. Thus, the total zinc loading to the Harbour should be reduced to 73 kg/day in 1989. The concentration in the Harbour water in 1989 should then be less than 0.01 mg/l.

VI.2.4 Phenols Loading

VI.2.4.1 Historical Actions

The annual average total loading of phenols discharged to Hamilton Harbour since 1974 is shown in Figure 23 along with phenols concentrations measured in the Harbour water. The loading has been reduced from about 2,600 kg/day in the early 1970s to about 38 kg/day in 1987 as a result of controls installed by the steel mills. The concentration of phenols in the Harbour water was less than 0.4 ug/l in 1987, well within the Provincial water quality objective of 1 ug/l.

VI.2.4.2 Current Actions

The sources of phenols discharged to the Harbour are shown in Figure 24 along with 1987 relative contributions. Essentially all of the phenols originate from the steel mills with Stelco representing 77% of the total load in 1987.

Stelco completed its program for control of discharges of

phenols in mid-1987. As a result, the total phenols loading to the Harbour in 1988 should be reduced to about 11 kg/day.

VI.2.5 Polynuclear Aromatic Hydrocarbon (PAH) Loadings

VI.2.5.1 Historical Actions

Knowledge of the historical loadings for PAHs is limited since technology for monitoring these chemicals in the concentrations found in the effluents (ng/l range) is a relatively recent development. The total PAH loading to the Harbour from point sources was found to be 1.8 kg/day in 1986, with the loading for benzo(a)pyrene being 0.068 kg/day.

VI.2.5.2 Current Actions

The wastewater treatment facilities installed to control conventional parameters are also efficiently removing PAHs. The PAH loading in 1987 was probably a fraction of a percent of what they were 20 years ago. The sources of the present discharges and their relative contributions to the total loading are shown in Figure 25. The control works installed by the steel mills in 1987 and the further works to be installed in 1988 are expected to reduce the PAH loading to the Harbour from point sources to less than 1 kg/day.

PAHs are not detected in the Harbour water column. They are, however, found in bottom sediments. Historical sediments are found to contain greater than 50 $\mu\text{g/g}$ of total PAHs as compared to 4 $\mu\text{g/g}$ in sediment deposited in 1987.

VI.2.6 Cyanide Loading

VI.2.6.1 Historical Actions

Essentially all of the inputs of cyanide to the Harbour are from the steel mills. With installation of pollution control facilities, the cyanide loading to the Harbour has been reduced from about 700 kg/day in 1967 to about 185 kg/day in 1987. The total loadings of cyanide to the Harbour since 1974 are shown in Figure 26. The sources of cyanide and their relative contributions in 1987 are shown in Figure 27.

VI.2.6.2 Current Actions

With completion of further control works by Stelco in 1987, the total cyanide loading to the Harbour in 1988 is expected to be 70 kg/day. Further control works being installed by Dofasco in 1988 should reduce the total cyanide loading to less than 50 kg/day.

In the latter 1970s when the loadings to the Harbour were in the order of 700 to 800 kg/day, occasional exceedences of the 0.005 mg/l Provincial Water Quality Objective for cyanide were found in the Harbour water column. With the reduced loadings, no exceedences would now be expected. Monitoring of Harbour water for cyanide will be carried out in 1988.

VI.2.7 Iron Loading Reductions

VI.2.7.1 Historical Actions

The iron loading to the Harbour in 1987 was about 4,000 kg/day, compared to about 20,000 kg/day in the early 1970s. The reductions have occurred as a result of installation of improved pollution control facilities by the steel mills. The total loading to the Harbour since 1974 are shown in Figure 28 along with the concentrations in the Harbour water column. The sources of the iron input and their relative contributions are shown in Figure 29.

In the late 1970s, occasional exceedences of the Provincial Water Quality Objective for iron (0.3 mg/l) were found. With the reductions of inputs that have occurred since then, exceedences are not now found.

VI.2.8 Suspended Solids Loading

VI.2.8.1 Historical Actions

The suspended solids loadings to the Harbour from the steel mills have been reduced from about 150,000 kg/day in 1967 to about 12,000 kg/day in 1987. The total loading from all sources since 1978 are shown in Figure 30. The sources of suspended solids and their relative contributions to loadings in 1987 are shown in Figure 31.

VI.2.8.2 Current Actions

At present, creeks are the largest source and represent about two-thirds of the total suspended solids loading to the Harbour. A study is now underway to identify the sources of suspended solids to the creeks and to determine abatement strategies.

Summary of Loading Reductions: Hamilton Harbour

The following tables (Tables 35-37) summarize the previous discussion of industrial and municipal loadings of ammonia and phosphorus and provide our best estimates of the improvements in water quality.

Table 35: Summary of Ammonia Controls: Hamilton Harbour

Action	Cost	Loading kg/day 1987	Proposed (Reduction)	Proposed Benefit	Status
Ammonia Loading reduced from 7500 to 3600 kg/day				Un-ionized Ammonia eliminated and oxygen improved in hypolimnion	
Specific Actions					
STPs					
Nitrification					
Hamilton	3 M. 5300 +350K/yr	(2790)	2510		by 1989 if pilot studies successful
Burlington	6 M. 1150 +100K/yr	(530)	620		dependent on consultant study
Industrial					
Dofasco	9 M. 244	(124)	120		By 1989
(recirculate plus diversion to STP)					
Stelco	4 M. 627	(477)	150		By 1988
CSOs					
	60 M. 200	(180)	20		1 controlled; control of remaining 25 dependent on funding (5 - 40 years)
Total Ammonia	82 Million	7520 (4100)	3420	un-ionized ammonia no longer exceeding objective oxygen in hypolimnion > 1.4 mg/l	

Table 36: Summary of Phosphorus Controls : Hamilton Harbour

Action	Cost	Loading kg/day 1987	(Reduction) Proposed	Proposed Benefit	Status
Phosphorus Control Hamilton Harbour				Algal Growth Water Clarity Oxygen improved	
Specific Actions					
STPs					
Chemical Precipitation					
Hamilton					
Iron	50K/yr	292	(65)		complete
primary	minor		(65)	162	pilot
Burlington					
	minor	42	(12)	30	dependent on pilot at Ham.
CSOs					
	Above	78	(73)	5	see above
Diffuse Source control					
	?	107	(55)	52	???

Summary of Total Phosphorus Controls from above
minor 519 (270) 249

Summary of Water Quality Improvements from Above Controls (Ammonia + Phosphorus)

Un-ionized ammonia < 20 µg/l

Oxygen Concentration in Hypolimnion > 2.8 mg/l

Phosphorus concentrations ~ 25 µg/l total P

Water Clarity Secchi disc >1.3 m

Further Phosphorus Control Options for Hamilton Harbour

Sand Filters				effluent P conc. to 0.3 mg/l
Hamilton	40 M	162	(66)	96 future
	+80 K/yr			
Burlington	15 M	30	(9)	21 future
	+30 K/yr			
Dual Point Chemical				effluent P conc. to 0.1 mg/l
Hamilton	1 M.	96	(64)	32 future
	30K/yr			
Burlington	1 M.	21	(14)	7 future
	30K/yr			

Summary of water quality Improvements with above possible future Phosphorus controls

Phosphorus Concentration 15-20 µg/l

Oxygen Concentration >3.3 mg/l

Secchi Disc Transparency >1.9 m

Table 37: Summary of Water Quality Options: Hamilton Harbour

	Other Loading Reductions Expected			Status
	1987 kg/day	change	New kg/day	
Zinc				Total Zinc loading 73 kg/day and Zinc conc. < 0.01 mg/l 1988-1989
Dofasco	30	(11)	19	
Stelco	49	(19)	30	
Phenol				Total Phenol Loading 11 kg/day 1988
Stelco	31	(26)	5	
PAH Loading from Steel Mills	1.8		< 1	1988-1989
Cyanide				
Stelco	119	(49)	70	1988
Dofasco	65	(15)	50	1989
Suspended Solids (Diffuse Source reduction)	31,000		16,000	?

VI.3 OVERVIEW OF LOADING REDUCTIONS: COOTES PARADISE

VI.3.1 Phosphorus Loading

VI.3.1.1 Historical Actions

Phosphorus inputs must be reduced to control algal growth. The average retention time in Cootes Paradise is only 2.7 days during the year. However, about a 20 day retention time occurs during the summer, low flow period. Control of available phosphorus inputs during the peak algal growing season of mid April to mid September is important.

The total loading of phosphorus to Cootes Paradise during the peak algal growing season has decreased from about 27 Kg/day in the mid 1970s to about 10.6 Kg/day in 1987 as a result of the expansion of the Dundas municipal STP. The average loadings of phosphorus to Cootes Paradise, from mid April to mid September, are shown in Figure 32 for the years, 1974 to present. Also shown in Figure 32 are the concentrations of phosphorus measured in Cootes Paradise. The sources of phosphorus inputs and their relative contributions in 1987 are shown in Figure 33 for the peak algal growing season.

VI.3.1.2 Current and Proposed Actions

The Dundas municipal STP remains the largest source of phosphorus input to Cootes Paradise during the peak algal growth season with 5.6 Kg/day being discharged in 1987. The Regional Municipality of Hamilton Wentworth is installing filters at the Dundas plant. Filters should reduce the phosphorus loading from the plant to about 3.5 Kg/day. Installation of the filters is expected to be completed in 1988.

The creeks represent the second largest source of available phosphorus with a loading of about 3.4 Kg/day. Further studies are required to identify the sources of this phosphorus and the abatement action that can be taken. Studies to identify the sources and the possible abatement measures are underway and should be completed in 1988. It is reasonable to expect, however, that at least a 50% reduction can be attained. The contribution from creeks therefore can probably be reduced to about 1.7 Kg/day.

The third largest input of phosphorus to Cootes Paradise is from Hamilton Harbour. The loading in 1987 is estimated to be 2 Kg/day. With the use of best available technology to control inputs to Hamilton Harbour, the contribution of Hamilton Harbour to Cootes Paradise would be expected to be reduced to about 0.7 Kg/day.

The fourth largest source of phosphorus discharge to Cootes Paradise is the Hamilton CSOs. The loading from this source is estimated to be 1.6 Kg/day during the peak algal growth season.

Installation of facilities to retain CSOs can probably reduce the loading from this source to less than 0.1 Kg/day.

With filters at the Dundas municipal STP, reduction of inputs from creeks by one half and elimination of CSOs, the available phosphorus loading to Cootes Paradise during the peak algal growing season would be reduced from 12.6 Kg/day in 1987 to about 6 Kg/day. The phosphorus concentration in Cootes Paradise would be reduced to about 58 mg/cu m. The turbidity caused by algae would therefore be reduced by 40%. Algal chlorophyll accounted for less than 10% of the variability of turbidity during 1987. Turbidity in Cootes Paradise is also impaired by silt.

With the addition of chemical just prior to the filters as well as at the front end of the Dundas municipal STP the phosphorus input from the Dundas municipal STP could be reduced to about 1.2 Kg/day. The phosphorus concentration in Cootes Paradise would then be reduced to about 38 mg/cu m.

A third option would be to pump the Dundas sewage into the Hamilton sewers and to shut down the Dundas plant. The total available phosphorus loading to Cootes Paradise would then be reduced to about 2.5 Kg/day during the peak algal growing season. The phosphorus concentration in Cootes Paradise would then be about 28 mg/cu m. The turbidity caused by algae would be reduced by about 60% from present levels. Table 38 summarizes the loading reductions for Cootes Paradise.

VI.3.2 Suspended Solids Loadings

VI.3.2.1 Historical

The sources of suspended solids and their relative contributions to Cootes Paradise are shown in Figure 34. By far the largest source of suspended solids loading is from the creeks, which represent greater than 90% of the total loading to Cootes Paradise.

Soil erosion adds to turbidity in Cootes Paradise. The most common practice in the construction of subdivisions is to, first, strip off the top soil. Sewers and water mains are then installed and the homes and streets constructed. The top soil is then replaced and the lots are sodded. Between the stripping of the top soil and resodding, the erosion rates are very high. With development, the water retention capabilities are reduced resulting in more rapid runoff of precipitation. The more rapid runoff, in turn, causes higher peak stream flows which results in increased erosion of stream beds and banks. As well, the trend in the farming community has been towards the planting of more row crops such as corn. Soil is less protected from erosion with these crops. Measures to control soil erosion include: settling basins for runoff from construction sites; storm retention basins to reduce peak storm flows; installing rip rap on creek beds and

banks susceptible to erosion and modifying farm practices to minimize soil loss. The study underway to identify sources of suspended solids and abatement measures to reduce loadings of suspended solids by way of creeks should be completed in 1988.

Carp also cause turbidity by stirring up the bottom sediments during their activities. They also uproot aquatic plants. The loss of aquatic plants results in wind and wave energy reaching further down into the water column and perhaps reaching the sediments. Cootes Paradise is shallow and approximately 70% of its sediment surface is susceptible to wind and wave resuspension of silt since the aquatic plants are missing. Carp control by commercial fishermen was promoted by the Royal Botanical Gardens during the 1950s and aquatic plants returned. Means of controlling carp will have to be determined if aquatic plants are ever to return to the open waters of Cootes Paradise.

Table 38: Summary of Water Quality Options: Cootes Paradise

Phosphorus Loading to Cootes Paradise

Action	1987			New	Status
	Cost kg/day			kg/day	
Dundas STP					
Filters	2.5	5.6	(2.1)	3.5	1988
	Million				
Diffuse Sources	?	3.4	(1.7)	1.7	??
CSOs	Above	1.6	(1.5)	0.1	dependent on funding
Summary of Water Quality Improvements				Total Phosphorus conc.	58 µg/l

Future Phosphorus Control Options for Cootes Paradise

Action	1988		New	Benefit	Status
	kg/day		kg/day		
Dundas STP					
Chemical	3.5	(2.3)	1.2	TP to 38 µg/l	future
Closure			0	TP to 28 µg/l	future

VI.4 REMEDIAL OPTIONS TO ACHIEVE STAKEHOLDERS' GOALS

The goal statement, limitations and options to achieve the Stakeholders enhanced and future uses for Hamilton Harbour are sequentially presented in three sections:

- 1) Fisheries
- 2) Wildlife
- 3) Swimming

VI.4.1 Fisheries

Goal: Water quality and fish habitats should be improved to permit an edible, naturally reproducing fishery for warmwater species. Water and habitat conditions in Hamilton Harbour should not limit natural reproduction and the edibility of cold water species.

VI.4.1.1 Limitations

The current conditions affecting the fishery in Hamilton Harbour are, in order of importance:

- 1) Un-ionized ammonia concentrations still exceed the Water Quality Objective during the spring.
- 2a) There is no suitable larval pike habitat (submerged plants) in close proximity to the Grindstone Creek spawning area.
- 2b) There is insufficient spawning habitat (emergent vegetation) in Cootes Paradise and Hamilton Harbour to support a restored pike fishery.
- 2c) Most of the sheltered littoral habitat in the west end of the Harbour (between the Lax property and the Desjardins canal) has been filled. This area appears to be the most important site in Hamilton Harbour for largemouth bass (85 percent were captured here).
- 3a) Submerged aquatic plants are absent or sparse in 55 percent of the available littoral habitat in Hamilton Harbour.
- 3b) Suspended solids concentrations in Cootes Paradise and Grindstone Creek exceed the "no effect" level of 25 mg/l.
- 4) PCBs, Mirex and mercury concentrations in a few of the fish species in the Harbour exceed the consumption guideline.
- 5) The hypolimnion is anoxic during the summer and will not support a cold water fishery throughout the year.
- 6a) The warm water fishery is dominated by alewife, White Perch, carp and Gizzard Shad. The impact on desirable species includes competition for food, predation, and habitat destruction.

- 6b) Populations of desirable warmwater predators (pike, largemouth bass, smallmouth bass, and channel catfish) are low in Hamilton Harbour.
- 7a) The benthic invertebrate community in profundal sediments is dominated by oligochaetes and will not support benthivorous cold water fish species such as whitefish.
- 7b) Profundal sediments are toxic to Pontoporeia, an important food source for some cold water fish species.

VI.4.1.2 Proposed Remedial Options

The projected responses in oxygen, water clarity, habitat and fish production to the remedial options have been taken from the Marshall, Macklin, Monaghan Ltd. report "Assessment of Proposed Remedial Action Plans for Hamilton Harbour Volume 1" (February, 1988). The options and responses are graphically depicted in Figure 35.

1: Un-ionized Ammonia Loading Reductions

Un-ionized ammonia concentrations exceed the Water Quality Objective of 20 $\mu\text{g/l}$ for the protection of aquatic life. Present loadings of ammonia are 7520 kg/day and must be reduced to at least 3600 kg/day to eliminate the toxicity to fish.

Present (1987) contributors of ammonia to Hamilton Harbour are:

Hamilton STP	5300 kg/day
Burlington STP	1150 kg/day
Dofasco	244 kg/day
Stelco	627 kg/day
CSOs	200 kg/day
Total	7520 kg/day

Completed or Nearly completed process changes will lead to the following reduced loads:

Dofasco	120 kg/day
Stelco	150 kg/day

The process changes will cost Stelco and Dofasco a total of (4+9) 13 million dollars.

Presently planned retention and treatment of CSOs will reduce the ammonia load from CSOs to:

CSOs	20 kg/day
------	-----------

The retention and treatment of 1 CSO has already been completed and 25 more require treatment. The cost of the treatment of all CSOs is 60 million dollars. Implementation could be completed in 5 years but is presently slated to occur over a 20 - 40 year period.

A loading of 3130 kg/day from the two STP must be achieved if the ammonia loading goal of 3600 kg/day is to be met. A pilot scale study is presently underway at the Hamilton STP to determine if such ammonia loading reduction can be achieved with the existing facilities. Halton is retaining a consultant to determine what will have to be done at the Burlington plant to obtain such a reduction.

Target ammonia loading from the two STPs must be:

Hamilton	2510 kg/day
Burlington	620 kg/day

The loading reductions at the two STPs, if implemented, may cost in the order of 9 million in capital expenses and \$250,000 in yearly operating costs.

2: Spawning and Nursery Habitat for Northern Pike.

The only available spawning habitat in Hamilton Harbour exists in the Grindstone Creek marsh. The area is 3.7 ha and provides a spawning to adult ratio of 0.06. Under ideal conditions, this ratio should be 0.3-0.4. An additional 26-36 ha of spawning habitat are needed to sustain an adult pike population, using 90 ha of adult habitat. The most appropriate area for marsh construction is immediately upstream from Sunfish pond. Pike spawn on emergent grasses during March or April, depending on the temperature. The emergent grasses are flooded during the spring snow melt but water levels in Lake Ontario during the spring are still low. Therefore, emergent grasses subjected to Lake Ontario water levels are unavailable for pike spawning. Enhancement of pike spawning areas will require either water level control or the selection of areas upstream far enough to be independent of Lake Ontario's influence. Restructuring the slope on the north east shore to accommodate fluctuating water levels and planting marsh grasses could provide an additional 9 ha of spawning habitat. Further marsh development is required upstream in the area of the Boardwalk marsh and in the Grindstone Creek delta. Remedial actions in the delta include the construction of several small islands to: provide sheltered littoral habitat for fish, limit sediment resuspension, provide appropriate slopes for marsh development, and channel sediments from Grindstone Creek into the Harbour (to reduce sediment accumulations in shallow water).

Although there were small numbers of adult pike spawning in the marsh in 1987, there is no suitable downstream nursery habitat to provide food and refuge for juvenile pike. The remedial actions proposed for the Grindstone Creek delta will encourage submerged vegetation in the delta and provide suitable food and refuge for larval pike emigrating from the spawning marsh.

Littoral Habitat - Quantity and Quality

There are only 199 ha of littoral habitat in Hamilton Harbour. Submerged vegetation is absent or sparse in 109 ha leaving only 90 ha of suitable habitat for desirable warm water fisheries. Most of the littoral habitat is along the north shore and is exposed to wind and wave action. Light penetration appears to be the most important factor limiting the growth of submerged plants. The presence of dense vegetation in the sheltered LaSalle Marina suggests that resuspension of bottom sediments and erosion along other parts of the north shore is responsible for much of the light extinction. The relative contribution of sediment and algae are unknown and research is needed to identify the source and impact of suspended particles in the littoral zone. This research is planned for the summer of 1988.

Apart from research to identify the source and extent of suspended sediments in the Harbour; remedial actions should be designed to create habitat by creating sloping shores or adding fill to deeper littoral areas. Protected embayments will encourage submerged plants, provide additional protection to the existing shore, and move the high energy wave impacts into deeper water. Restructuring the shoreline (and creating marsh and island habitats) have implications for boaters and property owners. Shoreline configuration will be determined in cooperation with interest groups.

Apart from submerged aquatic plants, the nearshore (<5m deep) zone of Hamilton Harbour is almost totally without structure. Structure, in the form of brush bundles, artificial reefs, or rock cribs provides feeding and refuge for adult and juvenile fish. Remedial actions to provide artificial structure in the littoral zone include the construction of brush bundles (3m X 3m square) submerged to a 3 m depth. The number and placement of these structures will have to be negotiated with other users.

Habitat construction along the south west shore (between Lax property and Desjardins Canal) is a high priority for fisheries restoration in Hamilton Harbour. This area appears to be the most important site for Largemouth Bass production in the Harbour. Reasons for this are unclear. Plant density is only moderate and the area receives direct discharge from a combined

Figure 32

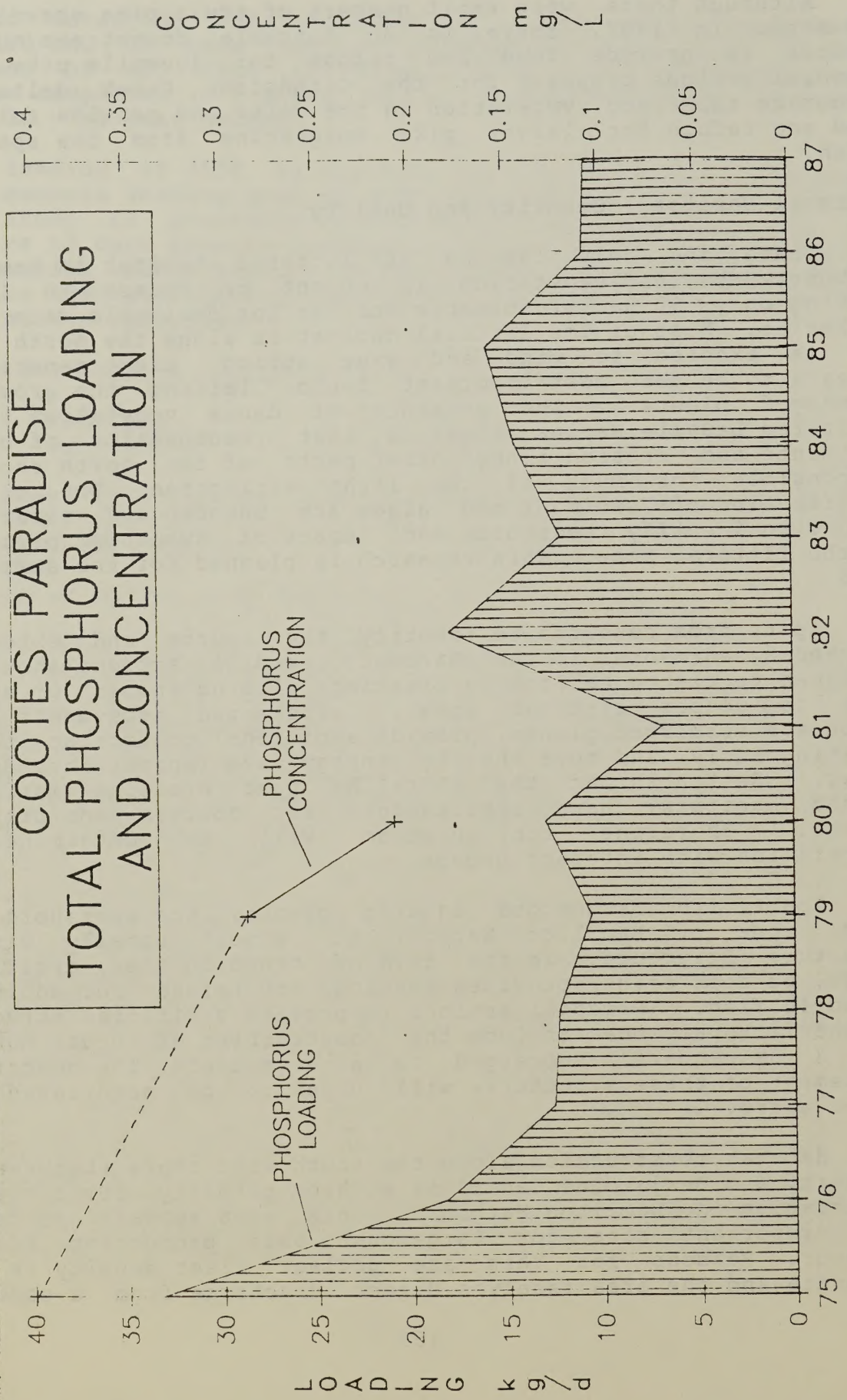
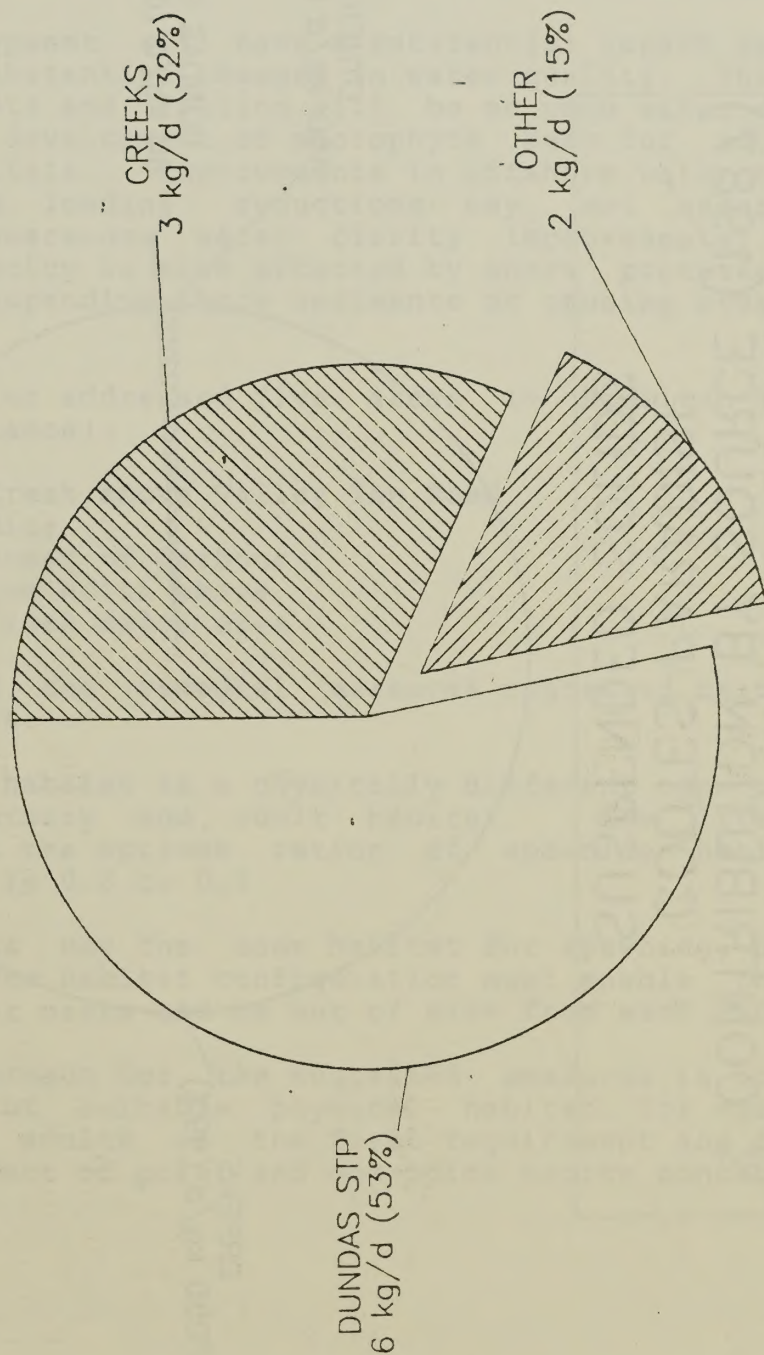


Figure 33

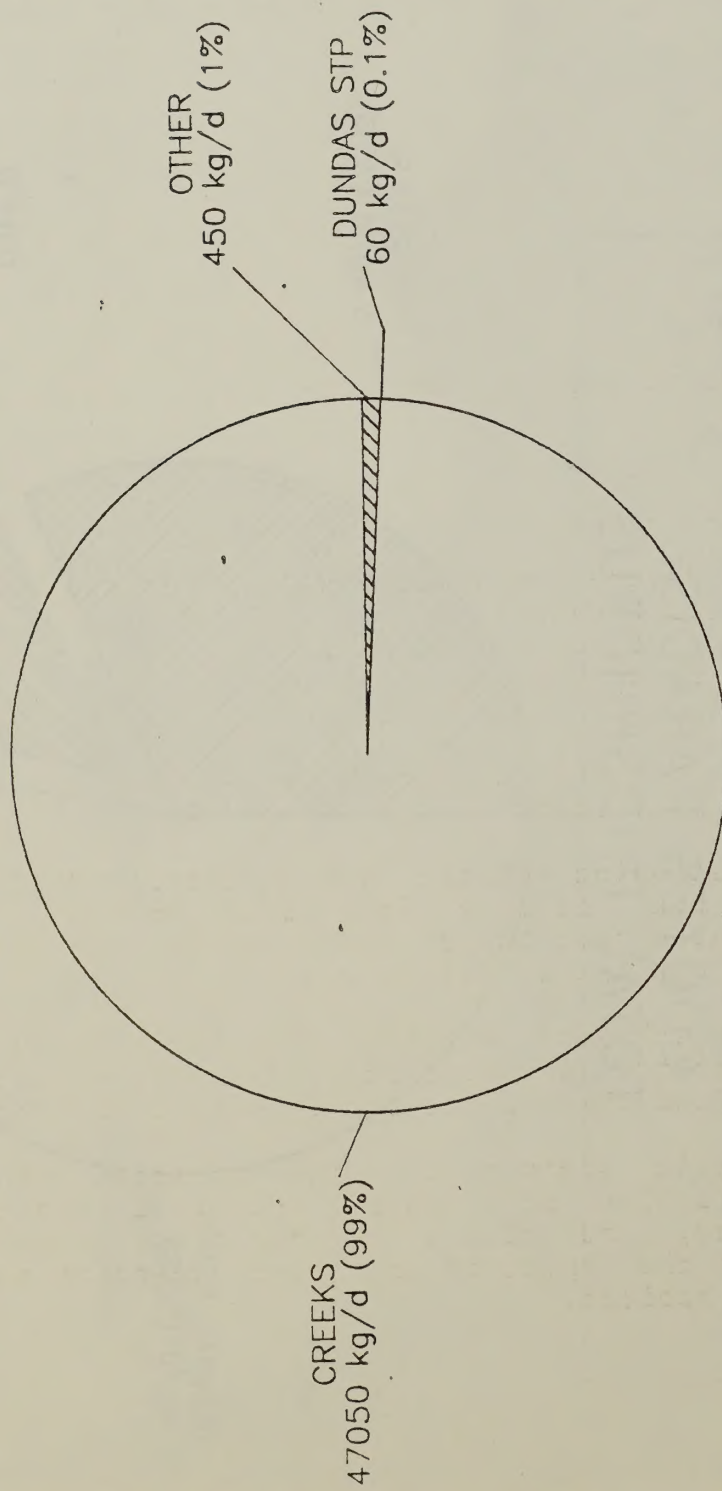
% CONTRIBUTION BY SOURCE (1987)
COOTES PARADISE
TOTAL PHOSPHORUS



TOTAL 1987 TOTAL PHOSPHORUS LOADING: 11 kg/d

Figure 34

% CONTRIBUTION BY SOURCE (1987)
COOTES PARADISE
SUSPENDED SOLIDS



TOTAL 1987 SUSPENDED SOLIDS LOADING: 47560 kg/d

sewer overflow. The most noticeable difference between this site and apparently similar sites along the north shore is the degree of shelter provided by the escarpment. Remedial actions in this area include landfilling to create additional littoral habitat along the west shore, restructuring to create more sheltered embayments, and brush bundles and rock cribs to provide fish "attractants". This area is the future site of the waterfront park and construction of habitats will be included in the design of the facility.

Habitat development will have a substantial impact upon the fishery, without substantive changes in water quality. The major impact of embayments and filling will be on upon water clarity and the associated development of macrophyte beds for adult and juvenile fish habitats. Improvements in offshore water clarity due to phosphorus loading reductions may not necessarily translate into nearshore water clarity improvements, since nearshore water clarity is also affected by shore processes such as wave energy resuspending shore sediments or causing erosion of the shore.

Fisheries restoration addressed five areas in Hamilton Harbour (in order of importance):

- . Grindstone Creek above Valley Inn Road
- . Cootes Paradise
- . Southwest corner of Harbour
- . the Burlington north shore
- . Grindstone Creek delta area

To understand the remedial measures suggested below, one must appreciate that:

- 1) Pike spawning habitat is a physically different type of area than pike nursery and adult habitat. The literature indicates that the optimum ration of spawning habitat to adult habitat is 0.3 to 0.4
- 2) Largemouth Bass use the same habitat for spawning, nursing and adults. The habitat configuration must enable the fish to defend their nests and be out of view from each other.
- 3) The basic approach for the suggested measures is to treat the creation of suitable physical habitat for spawning, nursing, and adults as the first requirement and then to assess the impact of point and non-point source control upon adult habitat.

Grindstone Creek above Valley Inn Road

This area is the only area in Hamilton Harbour where pike currently spawn (Broadwalk marsh). However, young pike require vegetated nursery areas close to the spawning area so that pike fry can travel from the spawning area to their nursery area without suffering major losses due to predation by other fish. Remedial measures for this area are:

- 1) enhancement of the spawning area (Broadwalk Marsh)
- 2) promotion of aquatic plants in the nursery areas- the Elbow and Sunfish Pond.

Creation of habitat in this area has been estimated at \$100,000 capital and \$10,000 yearly maintenance costs. The total available area is 17 hectares; current pike spawning habitat is 3.7 hectares; current nursery area is 1 hectare. The current spawning area could produce 1000-2000 fingerlings; however, nursery area is limiting. The enhancement of the spawning area (1 additional hectare) and promotion of nursery habitat (additional 1.3 hectares) could produce 1500-3000 fingerlings and ensure their survival.

Cootes Paradise

Pike spawning and nursery habitats do not exist in Cootes Paradise. Bass habitat is also minimal due to the lack of structure and submergent aquatic plants. Creation of isolated areas which can be manipulated for the promotion of aquatic plant growth is possible in the 100 hectares between Bulls Point and Princess Point. Detailed plans and feasibility studies would have to be performed to responsibly judge the fishery potential. Bass production could be 30 kg/hectare/yr from the cells. Incorporation of pike spawning and nursery habitats in the design would require water level manipulation and direct manipulation of the pike since normal Lake Ontario water levels would not provide flooded emergent grasses during spring which the pike require for spawning. The initial construction and annual maintenance costs are estimated to be 1 million dollars and \$50,000.

Southwest corner of Harbour

Land filling could create suitable habitats to a depth of 3.5 m. by shaping the shore to create embayments. Shore projections would create suitable areas for public access for fishing as well as swimming. Currently, there are 4 hectares of adult pike habitat and spawning, nursery, and adult bass habitat. The area is important since sport fish currently concentrate in this area of the Harbour and public access for fishing is easily incorporated into the two plans. Creation of 35 hectares of pike and bass habitat is possible at an initial construction cost of

1.7 million and yearly maintenance costs of \$30,000. Sport fish production in this area could be 50 kg/hectare/year.

Burlington North Shore

The north shore provides the largest potential area for adult habitat in the whole Harbour. However, the steepness of the shoreline and exposure to wave action which reduces water clarity appear to be the most important factors limiting submergent plants. The lack of underwater structure or complexity along the north shore is limiting the sport fish potential of the current vegetated areas. The placement of 12 brush bundles or rock-rubble underwater reefs could create 1 hectare each of structure at a cost of \$10,000 each (\$120,000 total) and annual maintenance costs of \$5000. The increase in structure and complexity would promote bass spawning and act as fish attractants. The underwater reefs alone would produce 600 kg/year. The increased production of sport fish in the presently vegetated areas is difficult to estimate.

Grindstone Creek Delta

The construction of islands in approximately 50% of the area to promote the growth of emergent and submergent plants and increase the complexity of the area could produce 1100 kg/year. The construction costs are estimated at \$200,000 and annual maintenance costs are \$10,000. The construction of the islands would be designed to ensure that the top of the islands would be completely out of the water during low water years and just below the water line during high water years. These areas would provide spawning habitat for bass and adult habitat for pike and bass.

3: Suspended Solids Reductions and Water Clarity Improvements

The most significant source of suspended solids to Hamilton Harbour and in particular to Cootes Paradise and Grindstone Creek, is stream loadings due to poor watershed practices upstream.

A Land Use Survey is currently being conducted for the watershed. The survey will identify areas prone to erosion due to current land practices. If some of the areas are under agriculture, then the Ontario Ministry of Agriculture has programs to assist farmers in reducing soil loss. Acceptable soil loss rates are 3 tonnes per acre, if the area is not adjacent to a watercourse, and 1 tonne per acre for land draining into a watercourse.

The Ontario Ministry of Agriculture has two financial incentive programs for Ontario farmers (OSCEPAP II and Land Stewardship Program). Land Stewardship is a program to provide

grants for the adoption of conservation farming practices that will enhance and sustain agricultural production and improve soil resources and water management. Soil structure, erosion control structures, conservation equipment and technology are included. This new 40 million dollar program is in the process of being implemented on Ontario farm land. The Ministry expects much activity in the spring of 1988. This complements the present 22 million dollar OSCEPAP II program which includes structures to control soil erosion, to protect highly erodible land, to build manure storage, milkhouse/milking parlour washwater disposal systems, and pesticide handling facilities.

Some of the erosion of soil will however, be from other sources besides agriculture. Urban construction practices and instream bank erosion will be important. The enforcement of existing programs for the control of soil loss from housing developments must be stressed. Instream bank erosion is the responsibility of the Conservation Authorities. Grindstone Creek was examined in the late 1970s and the areas and processes contributing to erosion of soils in the watershed were identified. Remedial actions were recommended. Some of those actions have been implemented.

Suspended solids concentrations in Cootes Paradise and probably Grindstone Creek appear to be elevated above the incoming source. For example, Spencer Creek flows into Cootes Paradise with suspended solids concentrations normally around 5-20 mg/l. This concentration is satisfactory for long-term survival of fish. However, Cootes Paradise open water suspended solids concentrations are around 100 mg/l. Resuspension of sediments from shallow areas in Cootes Paradise from wind, waves, water movement and carp is believed to be responsible for the increase. The contribution of algae to water clarity in Cootes Paradise is minor in comparison to the high silt concentrations. Loading reductions from the watershed will not resolve the elevated silt concentrations in Cootes Paradise over the short term. Past sampling programs in protected areas of Cootes Paradise have reported small improvements in water clarity (29 cm compared to 23 cm Secchi disc transparency) relative to open water (Bacchus, 1974). Therefore, it is unlikely that remedial actions to reduce loadings of silt or to reduce resuspension of silt by wind action would improve water clarity or reduce suspended solids concentrations sufficiently for either long term survival of fish or the regrowth of aquatic vegetation. The remedial measures to create aquatic vegetation suggested in the wildlife section and the fisheries habitat section are recommended.

Suspended solids concentrations above 25 mg/l are directly harmful to fish. Shallow water areas of the Harbour such as Cootes Paradise and Grindstone Creek delta have concentrations of suspended solids which exceed this level.

Water clarity is a function of algal cells and silt. Algal cells are responsible for only 10-30% of the total water clarity impairment in Hamilton Harbour and are responsible for less than 10% of the water clarity impairment in Cootes Paradise. Approximately 229 hectares of littoral area in Hamilton Harbour and 250 hectares in Cootes Paradise could support aquatic plant growth if water clarity was improved. Due to poor water clarity, less than 64 hectares in Hamilton Harbour support aquatic plant growths sufficiently dense to be considered fish habitat.

In offshore water, suspended solids control and water clarity improvements can be implemented by two means:

- 1) Phosphorus reductions to reduce algal growth;
- 2) Stream loading reductions of silt.

A pilot project is presently underway at the Hamilton STP to determine if process changes can be implemented at both sewage treatment plants to achieve a 50% phosphorus loading reduction at little or no cost. This will improve water clarity by 10%.

Control of CSOs, as described above, will achieve another 10% improvement in water clarity by reducing phosphorus loading and suspended solids loading.

Improved agricultural practices to reduce phosphorus loading and the suspended solids loading by one-half will improve water clarity by 20%. The adoption of conservation tillage and improved erosion control is a long term, technically feasible, objective. The implementation of measures to reduce soil erosion is dependent on improved soil management practices and the time frame and costs (~ \$1.5 M) for the final realization of the loading reductions is difficult to predict.

The minimum offshore water clarity (Secchi disc transparency) with the above controls will improve by 40 cm from 0.9 m to 1.3 meters.

Nearshore water clarity is reduced relative to offshore water clarity due to wave action and resuspension of silt, carp and proximity to stream inputs of silt. Prediction of nearshore improvements in water clarity as a result of offshore water clarity improvements is difficult. Cootes Paradise, for example, has a suspended solids concentration of approximately 100 mg/l and a Secchi disc transparency of 20 cm, but the two inflows into Cootes Paradise have suspended solids concentrations of only 5 mg/l and Secchi disc transparencies of 70 cm. Practical means of eliminating wind and wave resuspension of bottom sediments may only improve Secchi disc transparencies to approximately 30 cm in Cootes Paradise.

The mean nearshore water clarity could also increase by 40 cm. If so, aquatic plant habitat will increase by 28 hectares and the plant densities in previous areas (64 hectares) will increase, thereby, improving fish habitat in those areas as well. Therefore the above phosphorus and silt loading reductions could possibly result in 28 hectares of new habitat and improve the quality of the previous 64 hectares. Total habitat allowed by water clarity improvements discussed above would be 92 hectares. If the habitat construction projects are implemented, then the improvements in water clarity will improve the quality of approximately 120 hectares (Hamilton Harbour only).

Reductions in suspended solids concentrations in Cootes Paradise and Grindstone Creek delta sufficient to ensure adequate water quality for fish will not result due to reductions in loadings since the average concentrations in the inflows are low enough not to be of concern. The habitat construction projects could resolve the site specific elevations in suspended silt if wave and wind resuspension are significant factors and growth of aquatic plants in the new habitat occurs.

4: Edibility of the Fishery / Fish Consumption Advisories

Currently, large individuals of five species of fish in Hamilton Harbour have consumption restrictions due to high PCB, Mirex, or mercury concentrations. Salmonids from Lake Ontario will almost certainly be unsuitable for unlimited consumption. However, a comparison of 1972-76 data with 1981 data would suggest that improvements in fish PCB and Mirex concentrations have occurred. The fish analyzed in 1981 were one to two orders of magnitude below the PCB guideline. Unpublished data exists from 1985 that would confirm the trend in 1981. Contaminant levels are similar in white suckers (whole fish) from Hamilton Harbour and five locations around Lake Ontario. This may not be surprising since these fish are temporary residents in the Harbour and tend to reflect Lake Ontario conditions. The 1985 data are needed to confirm the declining PCB and Mirex trend in Hamilton Harbour fish. The Mirex consumption advisory is due to Lake Ontario conditions since there has never been a source of Mirex in Hamilton Harbour.

The contribution of Hamilton Harbour contaminants to the fish consumption advisories is unknown. The relative contribution of present loadings of contaminants versus historical loadings which have accumulated in the sediments of the Harbour is, therefore, also difficult to assess.

The fish consumption advisories are for chemicals that either originate in Lake Ontario or had at one time point sources in Hamilton Harbour that have since been eliminated. Some of the fish tumours appear to be related to chemical irritation, possibly by PAHs. PAH loadings have been dramatically reduced

but PAHs still persist in the sediments. Benthic invertebrates have increased in abundance and diversity and extent since 1964, but bioassays indicate that some of the sediments are toxic to some organisms but not others. Toxicity of the sediments to some organisms is alleviated by aeration of the sediment extracts. Snapping turtles had hatching deaths similar to other areas connected to Lake Ontario. Snapping turtles are long-lived animals (>50 years) and simply stress the need to eliminate persistent organic contaminants.

Remedial actions to improve dissolved oxygen conditions in the hypolimnion may provide access to contaminated benthos during the summer and result in increased contaminant levels in fish. There are no data available describing contaminant concentrations in benthic organisms in the profundal sediments of Hamilton Harbour. However, oligochaetes from Windermere Basin contained 4 mg/kg of PCB (approximately 3-4 times sediment concentrations). Mean PCB concentrations in Harbour sediment are 0.4 mg/kg. Deep water sediments are a potential source of PCBs and PAHs to the fishery. Research is needed to determine the bioaccumulation of organic and inorganic contaminants by benthic organisms throughout the Harbour. This work is ongoing and will be continued in 1988.

The MISA program will quantify the loading sources in the Municipal and Industrial sectors in Hamilton Harbour. The MISA program will also develop remedial actions and schedules for persistent toxic chemical loading reductions using the best available technology.

Once MISA has specified loading reductions and schedules for the municipal and industrial point sources in Hamilton Harbour, the agencies will have to deal with the historically, contaminated sediments. Pending the achievement of the virtual elimination of persistent toxic substances in the point source, the size of point source impact zones should be reduced to the maximum extent possible by the best available technology so as to limit the effects of toxic substances in the vicinity of these discharges. The Ontario Ministry of the Environment and Environment Canada are currently developing biologically-based sediment quality guidelines. The new guidelines will be drafted during 1988 and will replace the existing dredging guidelines for open water disposal of dredged material. The intent of these new guidelines is the protection of aquatic life and human health by ensuring no biological impact from in situ contaminants. The new guidelines will identify sediments where an unacceptable degree of sediment contamination exists thereby requiring a remedial action without the need to demonstrate site-specific biological impacts. These guidelines will be used to evaluate all sediments, not just in the context of dredging projects.

In anticipation of these revised guidelines, the following activities are recommended:

- (1) Complete the detailed resolution of the sediment area and volume potentially requiring remedial action (based on sediment toxicity, and the mobility and bioavailability of contaminants associated by sediments); and
- (2) Additional confirmation that biological effects are due to contaminants in the sediments and not due to continued point source loadings or due to the anaerobic nature of the sediments irrespective of the contaminant concentrations;
- (3) Pilot scale testing of alternatives to dredging and confined disposal as a means of effecting desired improvements in sediment quality and ecosystem health including in situ treatments and more sophisticated dredgate handling and treatment.

In situ treatments are attractive because they are cheaper than dredging. Both oxygen and chemical treatments of the sediments could prevent toxic metal release from the sediment into the overlying water. The in situ treatments may also detoxify the sediments for benthic invertebrates since the toxicity of the sediments may be due to the anaerobic nature of the sediments and not the contaminant concentrations. Improving the aerobic status of the sediments would assist in the bacterial metabolism of non-persistent organic compounds. Demonstration of the reduction of organic contaminants peculiar to Hamilton Harbour sediments as a result of improved oxygen conditions in the sediments has not been performed. In situ treatments will not decontaminate the sediments of toxic metals. Benthic invertebrates will continue to accumulate toxic contaminants. Fish which feed exclusively on benthic invertebrates will then also be subjected to sediment contaminants.

The anticipated sediment quality guidelines may demand that the sediments be decontaminated. At present, dredging is the only technology for decontamination of sediments. Dredging of one-third of the Harbour's sediments would require a CDF roughly twice the size of the current CDF in the Harbour. Construction of a new CDF would be difficult because of the deep water north of the current CDF. The cost of dredging would exceed 150 million.

5: Hypolimnetic Dissolved Oxygen

A desirable warmwater fishery is perceived to be a littoral based fishery with Largemouth Bass, Smallmouth Bass and pike as important recreational sport fish. Dissolved oxygen concentrations in the littoral zone are near saturation and are not limiting the warm water fishery. Although hypolimnetic oxygen is not essential for warm water species and is currently not limiting the attainment of the goal, anoxia is an important

factor affecting the benthic community. Major improvements in the abundance and distribution of benthic invertebrates in Hamilton Harbour have been observed during the last 20 years. The relationship between benthic invertebrate production in hypolimnetic sediments and littoral fish production is unknown. Presumably, large numbers of chironomids and other desirable species in the deep water sediments would contribute to the overall productivity of the Harbour. Benthic invertebrates are more tolerant of low dissolved oxygen conditions than fish. A hypolimnetic dissolved oxygen concentration of 1 mg/l would be satisfactory for most benthic invertebrate populations.

Hamilton Harbour sediments are acutely toxic to Pontoporeia and reduce feeding of Chironomus. These data suggest that remedial actions to improve oxygen concentrations in the hypolimnion may not be sufficient to establish a healthy benthic community. Research is needed to characterize the spatial distribution of toxic sediments before remedial options can be evaluated. Possible alternatives for contaminated sediments are presented in the Direct Treatment section.

Modelling the hypolimnetic dissolved oxygen concentration in response to loading reductions has identified the major sources of oxygen demand and oxygen supply. One of the unknowns is the length of time required for the sediment oxygen demand to equilibrate to new loading reductions; a delay of 10 years has been postulated. Under these conditions, the benefit of loading reductions in 1983-84 will not be realized until perhaps 1994. This delay in response makes it difficult to determine if further reductions will be necessary.

A hypolimnetic oxygen concentration of 4 mg/l should remain the long term goal for Hamilton Harbour. A short term goal of 1 mg/l for a restored benthic invertebrate community is recommended. The Writing Team also recommends improving dissolved oxygen models of the Harbour by combining the Klapwyk and Snodgrass model with Ng model and resolving the sediment oxygen demand delay. At that time, more confident loading reductions can be recommended to achieve the long term goal of 4 mg/l dissolved oxygen.

Other benefits of maintaining an aerobic hypolimnion would be:

- 1) ensuring that toxic metals are not released into the water from the sediments;
- 2) ensuring an abundance of benthic invertebrates which are part of the food chain in the diet of pike and bass.

Ammonia loadings are responsible for 40% of the oxygen demand in the Harbour water. With the implementation of the

above ammonia loading reductions, the oxygen concentration in the deep water of the Harbour will not go below 1.4 mg/l and might possibly be higher.

The phosphorus and silt loading controls discussed above for water clarity improvements will also increase the minimum deep water oxygen concentration by 1.4 mg/l to 2.8 mg/l.

Further improvements in the deep water oxygen concentration would be possible with the following phosphorus loading reductions:

Sand Filters and dual point chemical treatment at the Hamilton STP to reduce the effluent phosphorus concentration to 0.1 mg/l at a construction cost of 41 million and annual costs of \$110,000;

Sand filters and dual point chemical treatment at the Burlington STP to reduce the effluent phosphorus concentration to 0.1 mg/l at a construction cost of 16 million and annual costs of \$60,000.

The installation of sand filters and dual point chemical treatment at both STPs will ensure that the deep water oxygen concentration will not go below 3.3 mg/l. Offshore water clarity will also improve so that the minimum Secchi disc transparency will be 1.9 meters, an improvement of 60 cm from the water clarity achieved without sand filters and dual point chemical treatment. Nearshore water clarity will presumably also improve. Aquatic plant habitat could increase by 12 hectares. If habitat construction projects are not implemented, then water clarity improvements due to all loading reductions discussed could double the habitat in Hamilton Harbour (117 ha compared to 64 ha) at a cost of 117 million plus \$170,000 per year. Habitat construction projects will provide 132 hectares at this improved water clarity in Hamilton Harbour only.

Carp and White Perch Control

Attempts to encourage commercial fishermen to control carp and white perch in Hamilton Harbour would also be beneficial. Walleye populations did not successfully return in the Bay of Quinte until the white perch population was reduced by a winter kill. Since then the walleye have managed to maintain the upper hand and control the white perch population. Carp control was practiced by the Royal Botanical Gardens from 1950-60 and the aquatic plants made a comeback. Remedial measures to grow aquatic plants may meet with only partial success if high carp populations persist.

Interplay Between Habitat Options and Water Clarity Improvements

The above suggested construction projects could create approximately 6450 kg of sport fish per year at a construction cost of 3 million dollars and annual maintenance costs of \$100,000. Existing adult habitat for sport fish is approximately 64 hectares but is poorly utilized due to the lack of complexity. Spawning habitat is the most limiting factor. Creating spawning habitat for bass simply requires the incorporation of structure and complexity into the existing adult habitat. Pike production in Hamilton Harbour is limited by the lack of nursery habitat close to the existing spawning habitat. The above projects triple the amount of adult habitat (total 212 hectares) but more importantly ensure efficient utilization of the area by adult fish for spawning and protection of young fish. The realization of this quantity of habitat is independent of water clarity improvements.

Implementation of phosphorus loading reductions sufficient to obtain a phosphorus loading of 250 kg/day and a phosphorus concentration of 25 $\mu\text{g/l}$ will improve offshore water clarity by 40 cm. The mean nearshore water clarity could also increase by 40 cm. If so, aquatic plant habitat will increase by 28 hectares and the plant densities in previous areas (64 hectares) will increase, thereby, improving fish habitat in those areas as well. Therefore the above phosphorus and silt loading reductions could possibly result in 28 hectares of new habitat and improve the quality of the previous 64 hectares. Total habitat allowed by water clarity improvements discussed above would be 92 hectares. If the habitat construction projects are implemented, then the improvements in water clarity will improve the quality of approximately 120 hectares (Hamilton Harbour only).

Reductions in suspended solids concentrations in Cootes Paradise and Grindstone Creek delta sufficient to ensure adequate water quality for fish will not result due to reductions in loadings since the average concentrations in the inflows are low enough not to be of concern. The habitat construction projects could resolve the site specific elevations in suspended silt if wave and wind resuspension are significant factors and growth of aquatic plants in the new habitat occurs.

The installation of sand filters and dual point chemical treatment at both STPs will improve offshore water clarity by a further 60 cm. Nearshore water clarity will presumably also improve. Aquatic plant habitat could increase by a further 12 hectares. If habitat construction projects are not implemented, then water clarity improvements due to all loading reductions discussed could double the habitat in Hamilton Harbour (104 ha compared to 64 ha) at a cost of 117 million plus \$170,000 per year. Habitat construction projects will provide 132 hectares at this improved water clarity in Hamilton Harbour only.

VI.4.2 Wildlife

VI.4.2.1 Wildlife and Habitat in Cootes Paradise

Over the past few years, a broadly-based concern over the loss of wetlands in North America has emerged, and a political will to reverse this trend is developing. In Ontario, for instance, wetlands have recently been "untaxed" through a rebate programme, and the province will propose a wetlands policy in the very near future. The preservation, conservation, protection, and restoration of wetlands in the Great Lakes is one of the goals in the latest Great Lakes Water Quality Agreement.

The main contribution of wetlands to the overall ecosystem health is that they provide habitats for a very rich and uniquely adapted flora and fauna. It has been emphasized elsewhere in this document that the basin's wetlands, and therefore, its wetland-dependent wildlife, are rapidly deteriorating and disappearing, resulting in skewed species diversity and over population of scavenger-type fauna. If long term stability and balance are to be achieved in the resident wildlife community of the Hamilton Harbour area, then wetland habitat restoration must become an important goal. In addition, if migrating waterbird populations on the continent are to be restored, concerns that are reflected in the International North American Waterfowl Management Plan, then the contribution of such a strategic area as Hamilton Harbour, to the Atlantic flyway is vital.

Increasing the percentage of high quality wetland staging habitat available to migrants in the Great Lakes area is an objective of the North American Waterfowl Management Plan. The Canadian Wildlife Service includes the Hamilton Harbour basin in an area ranked as the second most important waterfowl staging area in Lake Ontario and as the fourth most important on the lower Great Lakes (Dennis and Chandler, 1974). Therefore, wetland habitat enhancements in Hamilton Harbour are important on a continental basis as well as a local basis.

Cootes Paradise and the Grindstone Creek mouth provide some of the best opportunities for achieving wetland restoration in the basin, because of their high degree of protection from human disturbance, urban development, and the occurrence of relatively contaminant-free sediments. Access and amenities for ancillary wildlife viewing and appreciation already exist.

Nevertheless, it is believed that water quality improvements expected as a result of the RAP process alone will not result in expansion of emergent marsh areas, at least in Cootes Paradise, given the current stresses on the aquatic vegetation here. This is not to say that greater control of creek runoff, retention facilities for CSO's and point source control of pollutants at the Dundas STP should not be implemented. Fluctuating water levels, basin morphometry, wind resuspension of accumulated sediments and the large migratory carp population are the primary

factors currently limiting the extent, species composition, and vigour of wetland vegetation in Cootes Paradise and probably Grindstone Creek mouth (S. Painter pers. comm.) These factors will not be appreciably affected by the planned actions to improve water quality mentioned above.

Since present circumstances will not permit natural recovery of the marsh vegetation, it is more practical to consider an engineered solution. This type of approach has been widely applied in the last decade on the Great Lakes. It is desirable, but probably not realistic, to expect that more than 50% of the total open water of Cootes Paradise will be suitable for revegetation (190 ha.). This area could be managed primarily for waterfowl though it is evident that other wetland-dependent wildlife will benefit. Should the sanitary sewage now treated by Dundas STP be rerouted to the Hamilton system, the west pond of Cootes Paradise would provide 10 ha. of shorebird habitat at critical times of migration by creating semi-permanent mudflats. Shorebirds utilize mudflats exclusively during migration for feeding and resting.

Diked Cells

One method of marsh rehabilitation, which has been used with success elsewhere, involves the construction of low-level dikes to enclose suitable areas. RBG has sought expertise from Ducks Unlimited to implement such a scheme. The proposed design is estimated to cost less than \$750,000. Through the use of pumps, water level can be manipulated inside the diked areas independent of fluctuating lake levels. Initially, complete drawdown would provide conditions for release of nutrients from the bottom sediment and foster the seed germination of aquatic plants. The area could be seeded or planted with desirable submergent plants such as Sago Pondweed, and emergents such as Giant Burreed, species which were common in Cootes Paradise.

Maintaining water levels to favour optimum submergent to emergent vegetation ratios (50/50) would then be possible. A wide variety of wildlife, such as ducks, wrens, terns, bitterns and blackbirds would colonize the newly created habitat. Reintroduction of formerly endemic wildlife could also be attempted. Sunfish, crappies and minnows could be released into the impounded areas to enhance the diet of herons, terns, and other piscivorous wildlife. The dikes will: (1) form a physical barrier to carp which would otherwise destroy the rooted plants; (2) impede wind resuspension of bottom sediments; and (3) provide dry ground for nesting waterfowl and other species. The marsh will be more productive than it is at present. Nesting waterfowl normally choose nest sites in residual herbaceous vegetation near water. This type of habitat is generally not available in Cootes Paradise which is, in essence, surrounded by upland forest.

Island Construction and Creation of Nesting Habitat

Additional nesting habitat could be provided by the construction of small islands which would serve as waterbird loafing areas and facilitate turtle basking. Nesting boxes for Wood Ducks and platforms for Ospreys could also be installed within the enclosed areas. The excessively low winter water levels, commonly experienced in Cootes Paradise are deleterious to invertebrates, submergent macrophytes and muskrats. These adverse effects can be avoided by water level control through the use of pumps. Muskrats for example, require at least 60 cm of water at their lodge site for survival in a cold winter (Errington, 1962).

Canada Goose Control

There are also indications that the resident population of Canada Geese in the western Harbour is reaching nuisance levels in specific areas. It is anticipated that the use of dikes by this species for nesting and grazing would increase unless measures are taken to discourage these activities. Dikes could be planted with a ground cover which is unpalatable to geese (eg. crown vetch, trefoil) and successful nesting could be limited by physical removal of eggs during the breeding season. It is also suggested that the current practice of reduced mowing of grassed areas on RBG's conservation lands, and the policy of discouraging the hand-feeding of geese be continued. The feeding of geese reduces their inclination to migrate.

Creation of Mudflats for Shorebirds

Once the Dundas STP effluent is diverted to Hamilton, the 10 ha west pond area of Cootes Paradise could be isolated from the other management areas by the placement of a berm across the outlet to create an area that could be managed as a semi-permanent mudflat. Flooding during summer would limit encroachment of emergent fringe vegetation, but spring and fall drawdowns, via pumping, would expose the mud flats and permit shorebird usage. This is especially important during spring migration when shorebird habitat is very restricted. The current high density of benthic invertebrates, the main food source of shorebirds, would be maintained for many years because of the high organic composition of these sediments.

Grindstone Creek Delta

There are no specific plans to enhance the Grindstone Creek delta for wildlife use by marsh restoration at present. However, there may be opportunities created as a result of efforts to restore warm water fisheries in this area. For example, Wood Ducks and Hooded Mergansers might be encouraged to breed there with the placement of nesting boxes in suitable locations. Ongoing consultation with wildlife biologists and the naturalist community is recommended.

VI.4.2.2 Wildlife Restoration: Hamilton Harbour

Wildlife & Habitat Goals

1. Hamilton Harbour

It is very difficult and probably unrealistic to define a specific population level which should be maintained for individual species of wildlife occurring on the Harbour. However, it would be desirable to maintain stable and healthy populations of wildlife species currently inhabiting the Harbour and to encourage the re-establishment of former wildlife populations. The term "stable" in reference to wildlife populations does not infer "unchanging", as natural wildlife populations undergo constant fluctuations in response to numerous factors. A stable wildlife population is one that is able to rebound from occasional perturbations. A healthy population is one that is successfully producing viable offspring in order to maintain itself.

The essential ingredients contributing to a healthy and stable wildlife population are an abundant and varied food supply that is free of contamination, and suitable nesting and resting habitats that is free from over-predation and disturbance. Remedial actions designed to improve water quality to a level suitable for re-establishing a warm water fishery will result in an abundant food supply (forage fish, invertebrates, aquatic macrophytes) for wildlife such as waterfowl, colonial waterbirds and shorebirds. The amount of nesting and resting habitat and the degree of contamination are factors for which specific goals can be defined.

Nesting habitats for colonial waterbirds currently exist in the Harbour at the Pier 27 CDF and Hydro Islands. The Pier 27 site is owned by the Hamilton Harbour Commissioners and is planned to be developed for port facilities when it has become full to capacity with Harbour dredgate material at a projected time of twenty years. The future of the waterbird colony at this site will be threatened by this development. An alternate site for the nesting colony should be developed in the Harbour to accommodate all the species presently nesting there. Existing population levels should be maintained except for Ring-billed Gulls. Ring-billed Gull numbers should be maintained at a level not exceeding 5000 pairs (currently 21,000 pairs). A 1 hectare area should be sufficient to accommodate the current populations of Double-crested Cormorants, Black-crowned Night-Herons, Snowy Egrets, Herring Gulls, Common Terns and Caspian Terns as well as a reduced population of Ring-billed Gulls.

2. Windermere Basin

During and following the planned dredging and disposal of the contaminated sediments in the Basin, an area should be developed to create a marsh wetland habitat suitable for the

nesting of waterfowl species and providing food and cover for migrating waterfowl, waders and shorebirds and to allow for the continued use of the Basin by wildlife currently using it.

Remedial Actions

1. Hamilton Harbour

A separate nesting area should be created to accommodate the colonial waterbirds currently using the Harbour. This area can be created by enlarging the existing 2 Hydro Islands to a combined area of 1 hectare. The area would remain as 2 separate islands. Nesting habitat specific to each colonial waterbird species should be developed. These are outlined below.

The islands would be enlarged by filling the shallow water around and between them (< 2 m chart depth) with clean rubble and landfill. At present the islands are each less than 0.1 ha in area and are 400 m distant from each other. The two islands can be enlarged to create irregularly shaped islands with an approximate area of 0.5 ha each. The islands should be built up to an elevation of at least 1 m above the high water mark (75 m). The shoreline around the islands can be sloped to create a littoral zone for the establishment of marsh vegetation which would provide food and cover for migrating waterfowl. Black Terns would be encouraged to nest in the marshy fringes by installing floating nesting platforms in sheltered areas. Concrete breakwaters should be built on the southwest sides of the islands to protect them from wave action caused by strong south or south-west winds.

Wooden nesting platforms can be built for Double-crested Cormorants on one island. These platforms would be constructed as braced breeding platforms attached to well anchored hydro poles. Platforms would be erected to provide enough nesting sites for 100 nests. The ground under and surrounding these platforms would be laid out with large driftwood logs, piles of rubble, etc. to provide ground nesting sites for about 100 more cormorant nests.

Selected species of shrubs would be planted in the centre of the other island to provide nesting habitat for Black-crowned Night-Herons. Night-Herons will nest in the lower branches of trees while cormorants prefer the higher branches. It is not desirable to have cormorants nesting above Night-Herons in the same trees because the trees will eventually die from cormorant feces and the Night-Herons will be forced out. Suitable shrub species for Night-Herons are lilac, dogwood or shrub willow. We estimate that an area of 500 sq. m would have to be planted with shrubs to provide nesting for at least 200 pairs.

The majority of the islands would consist of open level ground with a substrate of fine material (sand, soil or fine

gravel) to provide nesting sites for gulls and terns. To prevent the area from becoming overrun by Ring-billed Gulls, we suggest a monofilament wire grid be placed over an area to allow entry to Common Terns only (Blokpoel and Tessier 1984). An area of 500 sq. m would be required to support 500 nests. Decoys and recorded bird calls would be needed to attract terns to the area. The wires would have to be inspected regularly to remove entangled birds. Herring Gulls will nest around the periphery of the Ring-billed Gull colony and do not require special habitat manipulation.

Caspian Terns, which normally nest only in close association with Ring-billed Gulls, will not establish on the new site without difficulty. We know of no previous attempts to move Caspian Terns to a new colony. An area which would be flooded during early spring while Ring-billed Gulls are establishing nesting sites, but becomes dry in late spring would likely be colonized by Caspian Terns. An artificial pond which would be flooded during Ring-billed Gull nesting and pumped dry by an installed sump pump when Caspians have returned in good numbers should be developed. Decoys could also be set up to attract terns.

These colonial waterbird habitats should be developed before the existing colonies are pushed out by development. By creating these habitats there are no guarantees that the area will be used by the birds. Methods used to lure birds to the site could include: placing decoys, playing recorded bird calls or transferring birds to the site. No costs estimates for these plans have been developed at present. Custodians who would be responsible for the actual management of the site will have to be determined.

2. Windermere Basin

A plan to create littoral area for the development of wetland habitat in the Basin after the planned dredging operation has been developed and incorporated into the project guidelines and will not be detailed here.

VI.4.3 Swimming

The goals of the Stakeholders for swimming in the Harbour are as follows:

- Goal #1: providing that water quality meets appropriate health standards in the west end to support swimming as a use; water quality be enhanced to permit swimming, in the short term; and
- Goal #2 In the event that fecal coliform counts exceed water quality objectives for human contact, consideration should be given to using disinfectants and suitable membrane barriers to permit swimming, in the short term; and
- Goal #3 Hamilton Harbour Water Quality should be improved so that it (a) provides for swimming in certain areas of the Harbour over the long term; and (b) has no impact on water quality for swimming in nearshore Lake Ontario.

VI.4.3.1 Current Status - Swimming

Swimming is not normally practiced in Hamilton Harbour or Cootes Paradise due to limited public access and the Hamilton Harbour Commissions by-law prohibiting swimming in the Harbour.

The Lake Ontario beaches immediately adjacent to the ship canal, on both the Burlington and Hamilton side, experience high bacterial counts which result in closure. The Hamilton area beach is presently less extensively used than before, with the area known as Confederation Park experiencing greater use. While periodic bacteriological problems are experienced in this latter area, they are almost certainly not due to impingement by water from Hamilton Harbour.

VI.4.3.2 Limitations on Swimming

Legal

Swimming is presently illegal in Hamilton Harbour according to a bylaw of the Hamilton Harbour Commission.

Access

At present, there exist few, suitable shore-based safe access points for swimming in the Harbour (Carrolls Point area, Valley Inn area). There are three areas with immediate potential for swimming sites - (1) the former Lax property on the Hamilton side in the west end of the Harbour; (2) the waterfront area adjoining LaSalle Park on the Burlington side in the east-central area of the Harbour; and (3) the northeast portion of the Harbour adjacent to the Canada Centre for Inland Waters in Burlington.

Water Clarity

The most recent information on water clarity was collected in 1987. At that time, the secchi disc depth averaged 1.4 m, from April through October in the approximate middle of the Harbour. Secchi disc readings taken by Fisheries and Oceans Canada along the north shore, in shallow water during the summer of 1987 had a mean transparency of 0.95 m. Once a water depth of 2 meters was reached, the Secchi disc depth increased to 1.3-1.4 meters. The causes of the shallow light penetration are a combination of non-living solids, phytoplankton and a background absorption due to dissolved organics in the water. The decrease in water clarity inshore relative to offshore is probably due to wave action.

Bacteria

The sampling programs in the past provide insufficient information in nearshore areas in the western end of the Harbour to indicate its present feasibility for swimming. The open water sampling, although infrequent, indicates that bacteria counts in the center of the Harbour would not restrict swimming. Based on studies from other areas and the presence of CSOs in the inshore areas of the Harbour, bacteriological water quality in the nearshore areas is probably not suitable for swimming.

VI.4.3.3 Remedial Actions

Goal #2:

At present, swimming anywhere within Hamilton Harbour is not possible due to one or more of the following: legal prohibition, access, water clarity, and bacteriological water quality. Therefore, if swimming in the "Harbourfront" area is desired immediately, some artificial means of accomplishing this goal must be sought. This may be satisfied through the construction of the proposed facility at the former Lax property in Hamilton and through similar actions on the Burlington side of the Harbour in the area of LaSalle Park.

Goal #1 and Goal #3:

It is evident that the goal of swimming within the Harbour will only be accomplished if: the legal constraints are removed by the Hamilton Harbour Commission; water clarity is greatly improved by reducing solids inputs from all sources (especially from streams) and nutrients inputs (phosphorus) to limit algal biomass; bacteriological quality is determined for nearshore areas. In addition, access both to the water itself and to transportation facilities or arterial roads is essential.

In order to achieve goals 1 and 3 the following actions must take place:

1. Rescind or revise the Harbour Commission's bylaw prohibiting swimming in the Harbour. A revision might be introduced to reflect areas or zones within the Harbour where swimming could take place without

hindrance to, or danger from commercial shipping or recreational boating.

2. Suspended solids inputs must be dramatically reduced especially from streams (see Fisheries remedial action section). Nearshore water clarity will be reduced relative to offshore water clarity due to shore processes. Recommendations for shoreline modifications contained in the Fisheries remedial action section may also provide adequate nearshore water clarity for swimming.

Monitoring of nearshore water clarity relative to offshore water clarity must be initiated to determine if water quality objectives for swimming are exceeded.

3. The greatest source of bacteria to the Harbour is likely via the CSOs. Discharges from the STPs are likely of secondary importance. Storage of combined sewerage and subsequent treatment at the STP must be enacted. Since the western end of the Harbour was specifically mentioned in Goal #2, the program should begin with those CSO's which impact upon the western portion of the Harbour.

Monitoring of nearshore bacterial numbers must be initiated to determine if water quality objectives for swimming are exceeded.

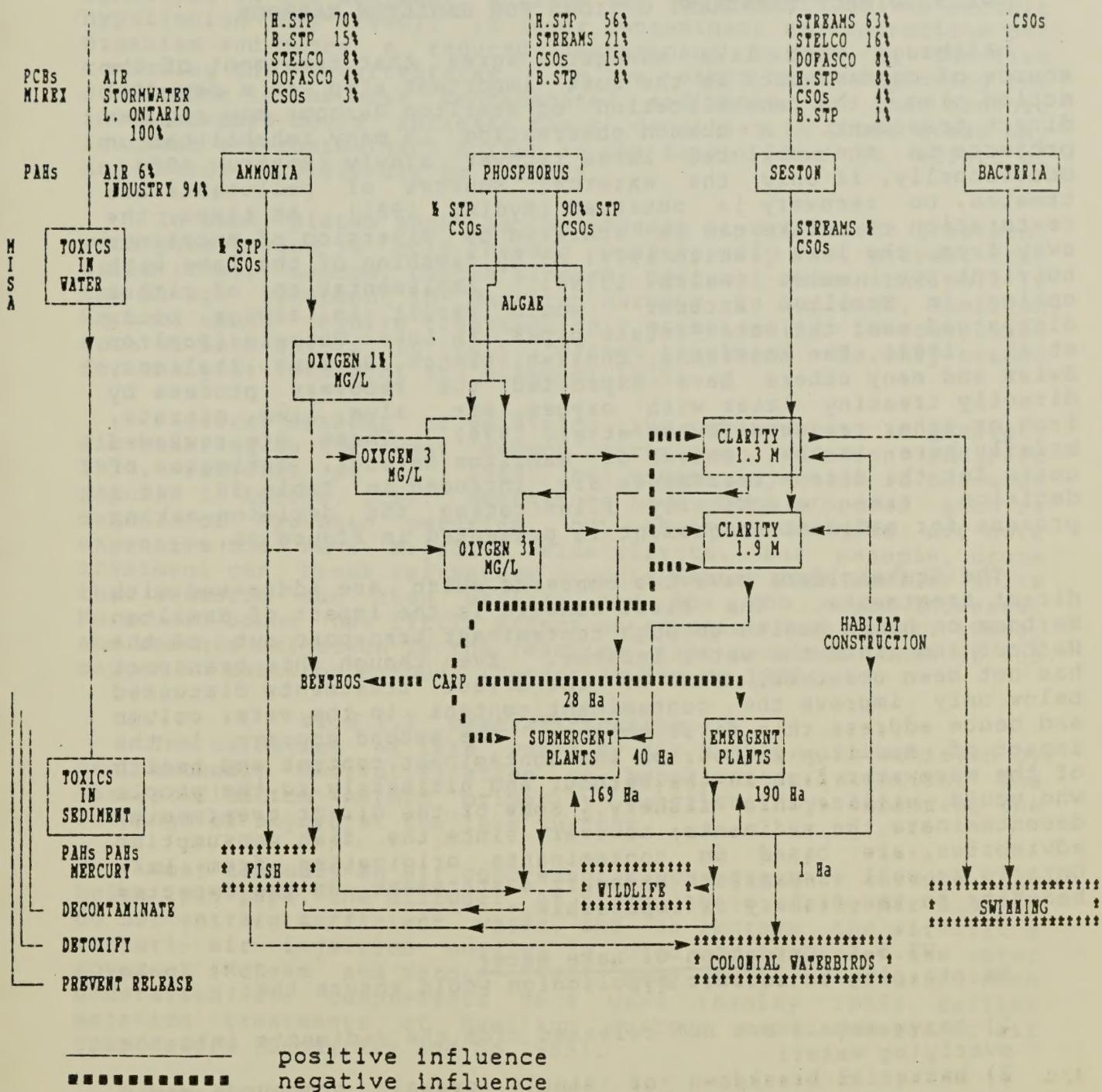
In order to achieve Goal #3, all of the 26 Hamilton CSOs must be "treated" in this fashion, either by building retention facilities and/or through "in-pipe" storage. In addition, better solids control at the STPs, through filtration, is essential to improve disinfection (i.e. more effective bacterial irradiation through contact chlorination).

The Regional Municipality of Hamilton-Wentworth has initiated a program for providing containment of sewage during times of precipitation to minimize CSOs. This program is described under the program for controlling ammonia discharges. It is estimated that \$60 million may be needed to control CSOs. At the present rate of commitment of funds, the Regional Municipality will take in the order of 20 - 40 years to complete the program. If funds were not limiting, the CSOs could probably be controlled within 5 years.

4. Access.

The proposed Waterfront Development, shoreline improvements recommended for the Southwest corner of the Harbour (for improved fishery opportunities), the treatment of the CSOs and improved watershed management will, hopefully, resolve the current water quality limitations on swimming.

Figure 35



VI.5 DIRECT TREATMENT OPTIONS FOR HAMILTON HARBOUR

Although most lake managers agree that treatment of the source of contaminants is the most important step in a remedial action plan, the rehabilitation of Hamilton Harbour may require direct treatment. A common observation in many rehabilitation projects is that polluted lakes recover slowly (Bostrum 1984). Occasionally, if only the external sources of pollutants are treated, no recovery is observed (Ryding 1981). At times, the restoration of a lake can be achieved by diversion of nutrients away from the lake (Welch 1977) or by flushing of the lake with nutrient-poor water (Welch 1979). Implementation of either option in Hamilton Harbour would result in sewage being discharged near the water intake pipes in Lake Ontario (Poulton et al. 1986). The Americans, English, French, Germans, Italians, Swiss and many others have expedited the recovery process by directly treating lakes with oxygen, air, alum, lime, nitrate, iron or other reagents (Dunst et al. 1974). These are reviewed briefly here in the context of Hamilton Harbour. Estimates of costs for the direct treatments are included in Table 39 and a decision tree graphically illustrating the decision-making process for sediment assessment is presented in Figure 36.

The Stakeholders have two concerns which are addressed with direct treatments. The first concern is the impact of Hamilton Harbour on human health through contaminant transport out of the Harbour and into the water intakes. Even though this transport has not been observed, some of the direct treatments discussed below only improve the contaminant content in the water column and hence address this first concern. The second concern is the impact of Hamilton Harbour on the contaminant content and health of the warmwater fish in the Harbour and ultimately to the people who would utilize this fishery. Some of the direct treatments, decontaminate the sediments; however, since the fish consumption advisories are based on contaminants originating from Lake Ontario as well as Hamilton Harbour, a statement on the expected benefits to the fishery is impossible.

VI.5.1 Oxidation of Lake Water

Maintaining an aerobic hypolimnion would ensure that:

- 1) heavy metals are not released from the sediments into the overlying water;
- 2) bacterial breakdown of simple organic compounds would progress (ie. only one of 14 PAH compounds, but PCBs and the majority of the PAHs not metabolized);
- 3) anaerobic nature of sediments which are currently stressing the benthic invertebrates would be improved.

However, except for simple organics, the sediments would not be decontaminated; and benthic invertebrates would still transmit contaminants to the fish. The higher benthic invertebrate

densities in the sediment surface as a result of an aerobic hypolimnion may result in lower contaminant concentrations per organism and hence a reduced contaminant burden to the fish consuming the invertebrates. On the other hand, improving the conditions in the most contaminated sediments so that benthic invertebrates could increase their densities in those areas may increase the contaminant burden in the fish. The net effect of any action is difficult to predict.

In some places such as the Thames River, direct treatment with pure oxygen is only needed occasionally to prevent fish kills (Toms, London, United Kingdom, personal communication). If the sewage treatment in Hamilton Harbour is improved, Hamilton Harbour could require treatment only occasionally. In some lakes such as Lake Ghirla in Italy, direct treatment was only needed for one year (Bianucci and Bianucci 1979).

Several methods of oxidizing lake water exist. In general, air bubbling is the most common technique (Lorenzen and Fast 1977, Pastorok et al. 1980), but oxygen injection is becoming popular in Europe. Other techniques have been proposed such as ozone, or hydrogen peroxide, but these techniques are more expensive and have negative side-effects. For example, ozone treatment can break refractory organic matter into smaller units that bacteria can then utilize and the BOD could increase. Moreover, ozone has little effect on ammonia (Haag et al. 1984), and ammonia oxidation is the reaction that consumes most of the oxygen in Hamilton Harbour (Snodgrass and Ng 1985).

VI.5.1.1 Destratification

The oxidation of lake water by air bubbling is achieved by two methods, destratification or hypolimnetic aeration. The destratification method primarily functions by enhancing the exchange of oxygen at the lake surface.

Most commonly an air compressor discharges air through tiny holes in a pipe, the diffuser. At times, these rising air bubbles do not entrain sufficient water, and to improve the air-lift a venturi air injection nozzle is used to enhance the water movement (McKean and Nordin 1986). Many failures occurred when undersized air compressors were used (Ashley 1985). Earlier aeration treatments of Hamilton Harbour used undersized air compressors (Snodgrass and Ng 1985).

Fans or water pumps are also used to enhance water movement and thus enhance oxygen transfer at the lake surface. Occasionally, the pumped water is blown through a fountain. A well placed fountain could be a symbol of the Harbour restoration but one fountain could not treat all of the Harbour and fountains could not be located around much of the Harbour.

Another variation of destratification uses connected twin shafts that are drilled into the lake bottom. Air is co-injected with pumped water down one shaft, the oxygen dissolves quickly at the great hydrostatic pressure at the bottom of the shaft, the air-water mixture passes to the other tube and the rising plume of nitrogen gas then acts as an air-lift pump. This system has potential in Hamilton Harbour in that minimal interference with shipping would occur.

VI.5.1.2 Hypolimnetic Aeration

The other major type of air bubbling is hypolimnetic aeration (McQueen and Lean 1986). In these systems the water column is not mixed and the process oxidizes only the water in the bottom of the lake. The advantage of hypolimnetic aeration is that the nutrient-rich bottom water is not mixed into the surface of the lake; thus, algal growth is not enhanced. Hypolimnetic aeration also enables the bottom water to remain cool; destratification warms the sediments and bottom water. Cooler sediments consume less oxygen (Holdren and Armstrong 1980) and fish prefer a cool, oxidized hypolimnion.

The most commonly used hypolimnetic system is the Bernhardt design. Air is injected into the bottom of a large pipe, air rises to a degassing box and then the oxidized water flows down a pipe back to the hypolimnion. This system has worked well in Germany (Bernhardt 1967, Bernhardt and Wilhelms 1975); however, the largest system in North America (in British Columbia) has had several problems that have delayed operation for a year (Ashley, B.C. MOE, personal communication). Research is being directed to enhance the dissolution of oxygen by improving the diffuser design. The design is simple and could easily be built locally. In Hamilton Harbour, the degassing box of a Bernhardt system would be a barrier to navigation and the box would have to be protected or removed in winter.

Atlas-Copeco has an hypolimnetic aeration design that is less restricting to navigation than the Bernhardt design. Air is pumped into an underwater mixing chamber (Fast et al. 1975). Under pressure the oxygen dissolves quickly. The residual nitrogen is vented to the surface via a small pipe. The pipe could be removed for the winter. Critics of this system say that nitrogen supersaturation that occurs could kill fish. The system is used in several sites and apparently fish do not die (Ripl, Berlin, West Germany, personal communication).

The Atlas-Copeco system appears to be the least expensive hypolimnetic aeration system; moreover, it is the only hypolimnetic system that is commercially available that has been used at several sites. In Hamilton Harbour, this system could only be used on the Burlington shore or the units would interfere with shipping. The Harbour Commission would consider implementing a no anchorage area for aeration. A local concern might be noise

from the air compressors on the shore of a residential neighborhood.

Locker International also has a hypolimnetic aeration system (Buhl, Zurich, Switzerland, personal communication). This system uses a water pump and a venturi to inject air. The Locker system is considerably more expensive than the Atlas-Copeco system, but a water pump is much quieter as well as easier and less expensive to operate than an air compressor. The Locker system can be built on shore, if deep water can be effectively pumped to and from the shore based aeration unit. This configuration would not disrupt shipping. Like all hypolimnetic systems, the Locker system has not been built on the scale that would be needed for the Harbour. The oxygen demand in the hypolimnion of Hamilton Harbour is about four times larger than the largest hypolimnetic air bubbling system that has been used to date (10 tonnes oxygen demand per day, Bernhardt design, in West Germany).

VI.5.1.3 Oxygen Injection

Oxygen injection is a relatively new lake treatment. The management options are quite different from air bubbling. Oxygen is cheapest near industrial centers; thus, oxygen injection should be evaluated for the Harbour. Oxygen injection can be divided into four main techniques: diffusers, side-stream pumping, equilibration tanks, or a deep-shaft.

The least expensive type of oxygen injection is performed with diffusers. The type of diffuser is critical. When large holes were used in Swiss diffusers, the large oxygen bubbles triggered the formation of nitrogen bubbles in the hypolimnion and these bubbles resulted in a mixing of the lake. When the injection was changed to a stainless steel diffuser in 1985, the smaller bubbles all dissolved; the lake was oxidized, and destratification did not occur (Buhrer, EAWAG, Switzerland, personal communication, Marki and Schmid 1983, Stadelmann et al. 1984, Joller et al. 1985). The reduction in eutrophication prompted managers to treat two more lakes in 1986. In a reservoir on the Savannah River (USA), oxygen injection with ceramic diffusers was effective; destratification did not occur (Schreiner 1986). The ceramic diffusers of the Savannah project often cracked. In Hamilton Harbour, NWRI used simple porous plastic hose (Linde design) in a trial near the Lax property. A localized oxidation of the Harbour was observed. Sediment resuspension was not observed. Diffusers do not interfere with navigation, but anchors would damage the diffusers.

The Savannah River project was larger than the Hamilton Harbour project (100 tonnes O_2/d vs. 40 tonnes O_2/d). The calculation of 40 tonnes a day assumes that only the hypolimnion of the Harbour would be treated and that stratification would not be broken. The largest Swiss project used five tonnes of oxygen per day (Buhrer, EAWAG, Switzerland, personal communication).

Little information is available on other large projects, such as the oxygen treatment of Hong Kong Harbour or the Paerl River in Washington State. Larger projects have been implemented in sewage treatment systems (Air Products, Detroit 380 tonnes O_2 /d; New Jersey 500 tonnes O_2 /d).

Side-stream oxygen injection involves the injection of oxygen into a pipe immediately after a water pump (Fast 1977, Linde). The system operates under moderate pressure; thus, oxygen concentration can exceed 40 mg/L. The equilibration tanks operate with lower pressure than side-stream, but they also use a water pump. Equilibration tanks are used in several sites in France (L'Air Liquide, Paris). These systems with pumps dissolve oxygen more efficiently in shallow water, but they have higher capital and operating costs than other oxygen injection systems.

Some of the systems that are designed to use air have been used to inject oxygen. The Atlas-Copeco system has been used successfully in West Germany for oxygen injection (Hansen, Berlin, West Germany, personal communication). The deep-shaft method could be used for oxygen injection. The deep-shaft and side-stream methods interfere little with shipping.

VI.5.2 Chemical Treatment of Hamilton Harbour Water

In Hamilton, the local availability of lime and iron should make the use of these chemicals more cost-effective than alum. The West Germans have added iron to aerated lakes to improve the precipitation of phosphorus (Ohle, West Germany, personal communication). The Dutch have added iron from pickle liquor to reservoirs to precipitate phosphorus (Peelen 1969). The British Columbia Ministry of Environment has found that additions of iron in pickle liquor to containers with sediment and water from Wood Lake prevented the release of phosphorus in both oxidized and reduced incubations (Nordin, Victoria, personal communication). Nordin hopes to treat all of Wood Lake in 1987 with pickle liquor. Wood Lake is about the same size as Hamilton Harbour.

Hamilton Harbour has relatively high iron concentrations; thus, maintaining high oxygen concentrations should precipitate iron. In laboratory incubations with Hamilton Harbour water and sediment, NWRI studies have found that oxygen injection precipitated iron manganese, copper, lead, and zinc. NWRI studies have shown that much of the iron in the Harbour is present in complexes that are not reactive (wustite, hematite); thus, oxygen-mediated precipitation of metals could be enhanced if more reactive iron compounds were added to the Harbour.

The addition of lime to hardwater lakes has been performed by NWRI in B.C. (Murphy et al. 1985) and Alberta. Lakes in Poland (Hillbricht-Ilkowska et al.) and USA (Knauer, Wisconsin) have been treated with lime to precipitate humic matter and thus

improve clarity. In deep lakes with long water retention times the effects are very striking; phosphorus and algae precipitate and the water column becomes clear. In the four NWRI treatments of western lakes, no fish were killed, and no adverse effects on zooplankton was observed. Lime treatment induces the precipitation of calcium carbonate (chalk). The precipitation of calcium carbonate is a natural reaction that precipitates phosphorus from many hardwater lakes (Murphy et al. 1983). In Hamilton Harbour, the effects of lime treatment on the water column may be short-lived. The flushing time of the epilimnion of the Harbour is 45 days; so a treatment of the water column would have the desired effect for a period perhaps half that time interval.

The length of time that direct treatment would be required is directly related to the rate of waste entry into the Harbour. The choice of techniques used for direct treatment should reflect the degree of control of source pollutants. For example in Wisconsin, lake managers will not use alum treatment if the source of nutrients is not greatly restricted (Knauer, Wisconsin, personal communication). The technique is too expensive for continuous use. Alum will keep nutrients in sediments for more than three years (Funk and Gibbons 1979, Foy 1985), but in trials in Mississippi with inadequate control of external nutrient loading, alum treatment did not suppress algal growth (Kennedy et al. 1986).

VI.5.3 Chemical Treatment of Hamilton Harbour Sediments

Chemical treatment of the sediments with lime, alum, and iron would precipitate heavy metals and phosphorus from the water column; coagulate the metals and phosphorus in the sediment and maintain the metals and phosphorus in an insoluble form so that release to the overlying water does not occur. However, successive treatments would be necessary to maintain the contaminants in an insoluble form. The sediments are not decontaminated and benthic invertebrates would continue to transmit contaminants to the fish. The benthic invertebrates are continually working the sediments and recent experiments illustrate the magnitude of their effect. In aquarium experiments with densities of oligochaetes similar to Hamilton Harbour ($10,000/m^2$), the worms covered a surficial white sand layer with 5-6 cm of sediments from below in 10 days. Mobilization of contaminants from this "new" sediment surface to the overlying water could occur, negating the desired effect of the chemical treatment. The present sediments in the more toxic areas of the Harbour (Figure 12) have high concentrations of aluminum (Al_2O_3 , 11%), iron (Fe_2O_3 , 17%) and calcium (CaO , 12.5%). Approximately 40% of the sediment is comprised of compounds that have the potential to adsorb or form complexes with trace metals which explains why release of trace metals to the overlying water has not been observed.

Perhaps lime is more useful as a sediment treatment. In NWRI laboratory treatments of Hamilton Harbour water and sediment, lime application resulted in the precipitation of lead, copper, iron and zinc. Although the NWRI study did not study cadmium, it is well known that cadmium is also bound tightly within the calcite lattice (Kitano 1978). Sealing the sediments with a chemical that prevents toxic metals from entering the water column would be an inexpensive alternative to dredging and disposal of contaminated sediments. The impact of benthic invertebrates in mixing the sediments, thereby mixing the lime into the deeper sediments needs to be addressed. The surficial sediment surface is constantly changing due to the bioturbation of the worms and sealing of the sediment surface to prevent contaminant release would be difficult.

Another chemical treatment of sediments that warrants consideration is nitrate injection. Nitrate injection into Swedish lake sediments has resulted in oxidation of the sediment (Ripl 1976, 1982); sediment oxygen demand and phosphorus release were suppressed.

VI.5.4 Physical Treatment of Hamilton Harbour Sediments

Physical barriers such as filter fabrics to prevent sediment pollutants returning to the water column are inappropriate for a Harbour. Sand would probably sink through the surface organic layer; however, a clay layer might be effective. Clay is more easily resuspended into the water column than lime; thus, turbidity could become a problem if clay was used to seal the sediments. Fly-ash has been used in some sites to seal lake sediments (Higgins et al. 1975, Theis 1979); however, many managers feel that fly-ash contains too many contaminants for this application (Mitchell, Edmonton, MOE, personal communication).

Other sediment treatments are:

- 1) Cover and Capping with sand, clay, silt, synthetic liners, or active cover material (limestone, greenstone, oyster shells, gypsum, ferric sulfate, alum, alumina, activated carbon, ion exchange resins;
- 2) Stabilization by grouting and sealing with cement, quicklime, silicates, bentonite;
- 3) Sorbents and Gels such as activated charcoal, resins, zeolites, polymers, foams and fibers.
- 4) sophisticated dredging by treatment and replacement.

A detailed discussion of each of these is beyond the scope of this report but a few comments would be useful. Capping would require at least 50 cm of material to isolate the contaminated sediments from the effects of benthic invertebrates. Sealing of the sediments is probably undesirable at present. Sorbents and

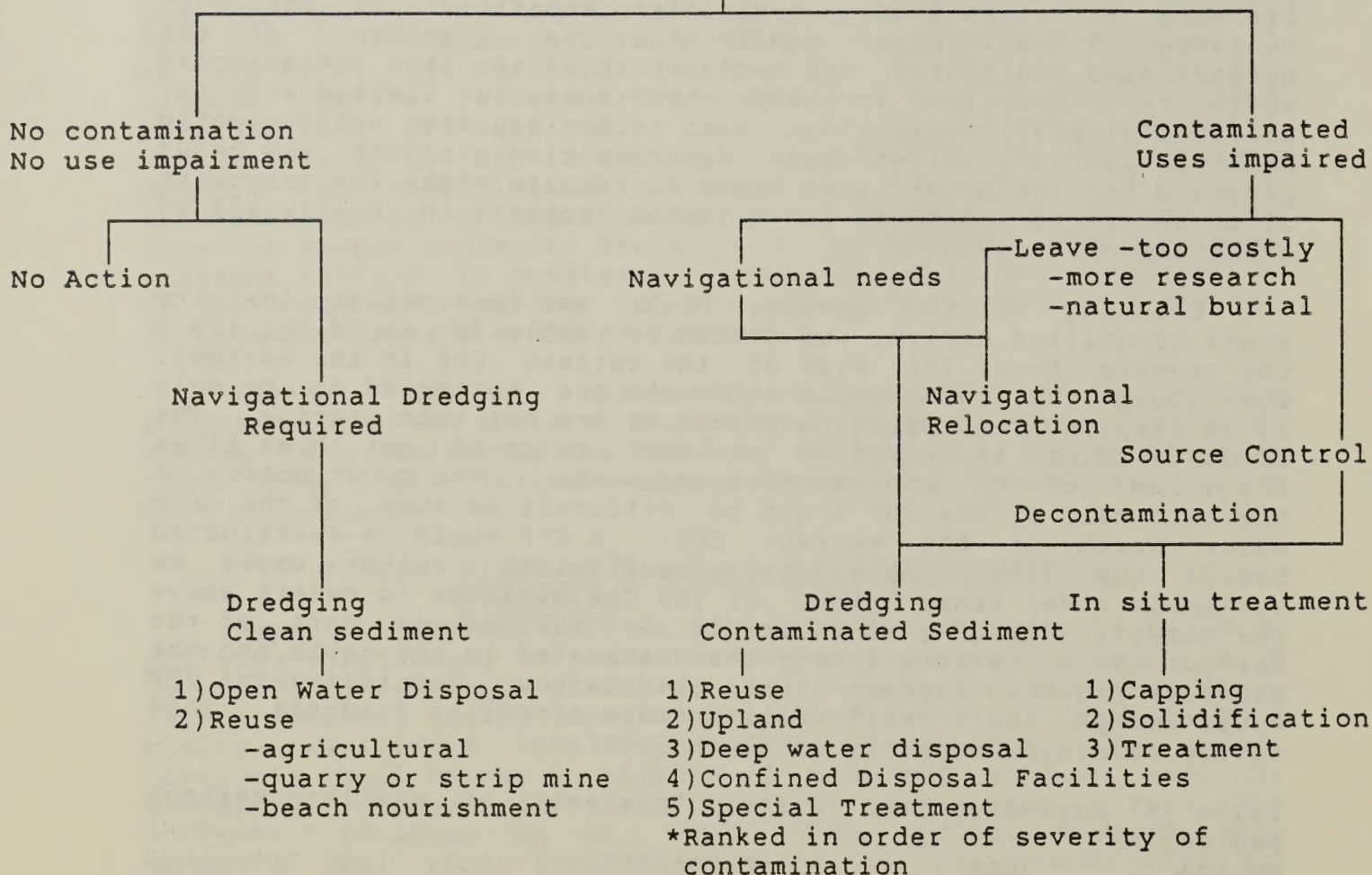
gels have been used for the cleanup of spills and as pretreatment prior to dredging but not for decontamination of sediments. Dredging of contaminated sediments; separation of the most contaminated sediments; confinement or treatment of the contaminated sediments; and replacement of the less contaminated sediments is practiced in Europe where there is limited area for confined disposal facilities. This technology does not currently exist in Canada. Pilot scale demonstration projects are being proposed for the Great Lakes Areas of Concern since the treatment of contaminated sediments is a common concern in nearly all of the areas of concern.

Dredging of the severe, high, and intermediate toxicity zones identified earlier and costed in Table 39 would require a CDF roughly twice the size of the current CDF in the Harbour. Even though the contaminated sediments are estimated to be only 33 cm deep, current dredging practices are not that precise. The dredgate volume is therefore at least twice if not three times the volume of the contaminated sediments. The construction of the berm wall of the CDF would be difficult because of the deep water north of the current CDF. A CDF could be constructed beside the CCIW complex but insufficient volume would be available (the final height of the CDF would be 10 meters above the water). Dredging of sediments in the deeper part of the Harbour would be more costly than estimated in the table and the estimate provided assumes that the Harbour Commissioners' CDF would accept the first 1 million cubic meters of dredgate. This is the remaining capacity of the HHC CDF.

Table 39: Estimates for Direct Treatment of Hamilton Harbour Sediments

Option	Cost	Comments
Dredging	\$	
3% of Harbour	3-9 million	The most toxic sediments
11% "	14-52 "	acutely toxic
33% "	50-150 "	intermediate toxicity
Chemical Treatment of the Sediments		
		one time costs/ repeats necessary
alum	1.3 million	uncertain effect
ferric	0.9 million	never used to reduce toxicity
calcium	1.1 million	but will slow release of metals
nitrate	16 million	into water column
Capping of Sediment		
Fly Ash	17 million	
Burial	0.6-1.8 "	availability of clean soil and costs unknown
Aeration of water column		
air	2.7 million	oxidation of sediments unlikely to take place but will slow release
hypo	4-40 "	of contaminants to water column
oxygen	0.4 "	

Figure 36
Sediment Assessment



Reuse of Contaminated Sediment:

- restricted depending on contaminants in question and levels
- agricultural, sod farms, quarry or strip mine reclamation, beach nourishment

Upland Disposal

- anticipated due to lack of CDFs adjacent to water body
- recreational (Ski hill), landfill

Deep Water Disposal

- mainly marine in water deeper than 30 meters in depositional basin

Confined Disposal Facilities

- most common option

Special Treatment

- to reduce disposal volume or concentration contaminants for hazardous waste disposal
- separation of material and return or use of less contaminated sand
- acid leaching of metal contaminants or solvent extraction of organic contaminants, ion exchange, thermal etc.

VI.5.4.1 Windermere Basin

Windermere Basin is a small basin about 40 hectares (100 acres) in size, situated at the south east corner of Hamilton Harbour. It became an enclosed body due to shoreline filling between 1954 and 1972. Although charts from 1915 showed shallow water in the area, the basin has become filled with solids, carried by Redhill Creek, to the point where mudflats now present an extremely displeasing aesthetic conditions. There is a concern that sediment may be scoured from the Basin as a result of normal water flows or flood conditions and carried to Hamilton Harbour.

Although the Redhill Creek watershed is the least urbanized of the three serving the city, it contains about one-half of the sewered area of the city. It therefore can carry significant amounts of urban as well as rural drainage in addition to the effluent from the municipal STP. The STP and non-point sources entering Redhill Creek contribute both toxic contaminants and suspended solids.

At the end of 1982, MOE published a report on the data accumulated to that time (MOE, 1982) which concluded that the sediments in the basin were heavily contaminated. Although there was approximately one million cubic meters (m^3) of organic sediment in the basin, the contaminated sediments appeared to be limited to the top 70 cm, or some 280,000 m^3 . Of concern was the potential effect of these sediments on wildlife, as large numbers of waterfowl and shorebirds are attracted to the Basin. Section IV.3.4.1 describes the specific concerns. Additionally, there was the potential to scour contaminated sediments out into the Harbour, although a water quality problem in the Harbour resulting from the contaminated sediments, has not been demonstrated.

Public opinion heightened and demanded a solution. As a result, the Windermere Basin Technical Advisory Committee (WBAC) was formed to evaluate alternative solutions. Members represented the Hamilton Harbour Commission, Ministry of the Environment, the City of Hamilton, the Regional Municipality of Hamilton-Wentworth, the Hamilton Regional Conservation Authority and Environment Canada.

In 1984, Environsearch Limited, was retained to evaluate solutions and new data. It concluded that resuspension and transport of contaminated sediments out of the Basin was indeed occurring under spring runoff conditions and thus abatement actions were warranted (Environsearch, 1984). The following options for remedial measure were considered by the WBAC:

- 1) Complete dredging of the contaminated sediments and debris from the basin. This would remove existing contaminated sediments, improve the appearance of the basin

and increase the trap efficiency of the basin to over 50%. However, dredging would destroy existing habitats for wildlife. The cost of removal and disposal of the contaminated sediment was estimated at \$20 to \$30 million for 1986.

2) Partial dredging of the most contaminated sediments combined with confined disposal within the Basin. This option would have similar results if specified precautions were followed, and would improve use by wildlife, depending on the design of the containment facility. The cost was estimated at \$4.4 to \$7 million, depending on the disposal requirements.

3) Creation of an artificial marsh in the Basin. This would enhance the aesthetics and reduce the nutrient and contaminant flow during the growing season. The marsh would also create a habitat attractive to wildlife. No estimates were made on the cost. The drawbacks were: a) A marsh does not provide treatment during the winter; b) resuspension of sediments during spring run-off may occur; c) the wildlife attracted to the marsh may take up contaminants; and d) the high sediment load from Redhill Creek will continue to fill up the basin.

4) Diking the narrow mouth of the Basin to raise the water level. This would be a temporary solution to increase the retention of water and improve the water discharged. It might also accentuate flooding problems. No cost was available.

From an environmental and financial point of view the Advisory Committee decided that a partial dredge and fill (#2) would be the preferred solution.

Subsequently, the Wastewater Technology Centre of Environment Canada was contracted to carry out a study to determine the environmental significance of in-water disposal of the dredged sediments. The conclusions reached by the Centre were:

1) there is the potential for contaminant migration from the existing situation, and therefore abatement actions should be undertaken;

2) the sediments are not hazardous wastes under Ontario Regulation #309;

3) the leachate from the sediments exhibits a very low potential for contaminant mobility (leachate meets drinking water criteria).

Thus, physical containment of the dredged sediments without chemical stabilization was considered environmentally suitable (WTC report).

The final report of the Windermere Basin Technical Advisory Committee recommended a partial fill and dredging solution without chemical stabilization of the sediments. The current estimate of this work is \$4.5 million. Periodic dredging will be required as further sedimentation occurs. In the long term as controls on point and non-point sources of contaminants and suspended solids in the watershed are implemented, the need for periodic dredging should decrease.

The Interim Stakeholders Report recommended that the Windermere Project be considered separate from and proceed in advance of the overall RAP, providing the Ontario and Federal Ministers ensure full public consultation and hearings on the alternatives.

Environment Canada, Ontario Ministry of Environment, City of Hamilton, Region of Hamilton-Wentworth and the Harbour Commission have agreed to provide \$1.25 million, \$1.25 million, \$750,000, \$750,000 and \$500,000 respectively, to fund the clean-up project. The Hamilton Harbour Commission have agreed to be the project proponent and to meet the requirements of the Federal Environmental Assessment Review Process (EARP). The Hamilton Harbour Commission have retained Marland Engineering to undertake the design of the confined disposal area, the berms and overall shape of the Basin. Data collection and preliminary design for the project were completed in February 1988. A physical model is to be tested by the National Water Research Institute, CCIW to refine the preliminary design. The goal is a design which maximizes the open water area and the settling capacity of the Basin. Sloped banks of the berms suitable for wildlife habitat are being considered in the design.

Through a Special Services Agreement with the Hamilton Harbour Commission, the Department of Public Works is responsible for ensuring the Environmental Review Process requirements are met and for arranging public consultation. Two open houses are planned for mid-April. Following public input the Initial Assessment Report will be finalized by the end of April 1988. Stage 1 of the construction could begin by June 1988, with completion of the two year project scheduled for March 1990.

VI.6 INFORMATION, DATA AND RESEARCH NEEDS

VI.6.1 Contaminated Sediment in the Harbour

Sediments in the Harbour are contaminated from industrial and municipal effluents, from urban runoff and from rural drainage over many years. The concentration of contaminants in the sediment is generally higher than the guidelines established for open lake disposal. Hence all material dredged for navigation purposes is placed in a CDF at the east end of the Harbour.

While the Harbour shares this general problem with almost all of the 42 Areas of Concern, there is some uniqueness in that a major portion of the contamination is iron from the iron and steel industries. It has been contended that this iron is helping to bind phosphorous into the bottom sediments so that it can far less easily be released to the water column again.

It should be noted that the current guidelines for dredging only come into effect if the material is to be moved. It should also be noted that it is likely that no new natural sediments from the watershed would meet all the guidelines. Nor is any extensive dredging going to eliminate all sediment that does not meet these guidelines.

The guidelines have little scientific basis and are currently being revised.

The principal concerns for the sediment are:

1. The design of the confined disposal facility currently in place eliminates shallow water habitat. However, current plans are only designed to accommodate normal navigational needs to 2000 A.D. There is a conflict between habitat loss and adequate disposal of contaminants.
2. The contaminants in the sediments could be the source of contaminants in fish that live in the Harbour, fish food organisms; and the reason for the decrease in number and variety of bottom organisms.
3. The contaminants in the sediments might continue to be a source of contaminants after the point sources had been reduced to levels comparable to (or less than) the material loading to the water column from the sediments.

Scope of Impact

Most tested solutions to contaminated sediment problems are some form of dredging. Even the most basic sort of dredging for 1/2 of the Harbour costs approximately \$1 billion.

Treatment of the sediments in place is not a well developed or tested technology. Lime, alum, burial techniques, oxygen or ferric chloride injection are all possibilities, which, though less expensive (by orders of magnitude) are experimental in nature.

In addition, each technique may have some potential for environmental impact that will require assessment before implementation.

Barriers to the Making of more informed Decisions about Contaminated Sediments

1. The link between contaminated sediments and the effects on biota needs clarification (how, where, how much).
2. The relative importance of current loadings of contaminants to the Harbour to historic sediment sources.
3. What constitutes an adequate demonstration of the potential for effects on biota?
4. Inadequate data on the horizontal distribution of contaminants (are there hot spots?) and the vertical profile of contaminants in sediment layers to readily identify cost-effective strategies or to compare current loading with total amounts currently held in all the sediments.
5. What is the difference between the effect of sediment oxygen demand and chronic sediment toxicity on biota?
6. Assessment of sediment treatment or burial techniques suitable for Hamilton Harbour and in-situ water column treatment effects on sediment contaminant mobilization.

VI.6.2 Eutrophication, Dissolved Oxygen Water Clarity and some related impacts.

For its size, Hamilton Harbour has been intensively loaded with nutrients and ammonia. While the extensive injection of water from Lake Ontario modifies the situation markedly, the primary productivity of the Harbour is high and the dissolved oxygen content of the hypolimnion in summer is at (or close to) zero for long periods.

The result is that there is an algal contribution to the lack of clarity of water in the Harbour, and summer oxygen levels that do not meet jurisdictional standards for dissolved oxygen (4 to 6 ug/l).

While phosphorus and ammonia loadings to the Harbour have been substantially reduced in the past 4 to 5 years, the observations available do not confirm any improvement in the dissolved oxygen conditions. A lag time of up to 10 years may obscure the impact at this time (1987). Perhaps year-to-year natural variations in the uncontrolled conditions (sunlight, natural heating of Harbour water, thermocline depth or harbour-lake water exchange) may obscure the trend until more summers have passed.

A response in surface chlorophyll concentrations is now evident. Its contribution to water clarity does need clarification, however, in order to assess what additional measures are possible to improve water clarity in the Harbour.

Existing models of the relation between phosphorus and ammonia loadings, and dissolved oxygen, suggest a very modest improvement in D.O. for possible loading reductions.

The Questions

1. Are there more efficient ways to treat ammonia? or phosphorus?
2. What is an appropriate final goal for minimum dissolved oxygen conditions for the Harbour?
3. How can the oxygen response of the Harbour to improved point source and internal loadings of phosphorus be better assessed.
4. To what degree will control measures for P and NH₃ contribute to resolution of other issues?

Scope of Impact

Remedial measures for phosphorus and ammonia involve a wide variety of additions to treatment of sewage, management of combined sewer overflows and land use modifications in the watershed. Ammonia control is viewed out of concern for its toxic properties, CSO improvements benefit toxic controls, suspended sediment control, and unsightly flotsam and bacteria control. The proposals for these measures potentially total just over \$1000 million.

Barriers to the Making of more informed Decisions to Eutrophication

1. An improved assessment of the relation of algal concentrations, seston characteristics and light attenuation (water clarity).

2. Better data defining the sediment budget of the Harbour.
3. A more extensive basis for assessment of the response of Harbour oxygen conditions to reduction of loadings of phosphorus and ammonia, based in models, data analysis and/or data collection.
4. Demonstration of treatment technology for NH_3 and P.

VI.6.3 Fisheries (Warm Water, primarily)

The Harbour currently has 50 species of fish that reside there at some time of the year. Predominant species are the less desirable forage types (e.g. carp). The full potential of the Harbour is not being realized. Habitat is a key factor.

The Questions

1. To what degree can the overall productivity of the warm water fishery be improved?
2. Can the species balance of the fishery be improved in terms of the more desirable fish?
3. How sensitive is the fishery to development?
4. How healthy and edible should the fishery be?

Scope of the Impact

The fishery is taken to be one of the important bell-weatheres of the 'health' of the aquatic ecosystem in the Harbour.

Cost to ameliorate the existing situation are of the order of \$10 million in the area of habitat restoration. Improvements beneficial to fish will be realized from improvements in toxic chemical controls and water clarity improvements (costed above) though the former is not yet well quantified.

Additional costs or foregone development may accrue in the future if sensitive habitat coincides with the areas deemed necessary to be modified for development.

Barriers to the Making of more informed Decisions about Fisheries

1. Need to develop a better relation between fish production and habitat type.
2. Need strategies to reverse from forage to predator predominance.
3. Need to understand the impact of heated effluents on fish.

Current Research Activities

The Remedial Action Plan must be considered as a process which is evolving over a period of time. As the goals, problems and options for the harbour are discussed among the scientists and Stakeholders and with the public they become clearer and more focused. The end result will be a plan which contains an implementation schedule for restoring beneficial uses.

Some of the limitations for achieving the goals have been identified and options for eliminating or reducing their impact have been outlined in this report. These measures should be reviewed and considered for implementation. However, there are a number of problems which are not fully understood and for which solutions have not been found. The writing team and other scientists from the participating agencies are continuing to investigate these areas in order to understand how they influence water quality. For instance remedial measures for contaminated sediments cannot be selected until further studies are completed. There are some measures that are experimental in nature which should be tested on a pilot scale before they can be considered as a viable options.

Projects planned for 1988 include:

- A. Last year's successful introduction of pike to study habitat preferences and their ability to survive in the harbour will be expanded in 1988.
 - 1. Five hundred northern pike, including 15 with radio transmitters will be released. The greater numbers will enable growth rates to be measured and also indicate what impact a pike fishery may have on the yellow perch populations.
 - 2. Underwater dives will be conducted to survey the density of fish numbers in various habitat and to more accurately predict production rates.
- B. Several studies are planned to expand the understanding of the sediments and effect of contaminants.
 - 1. Lead-210 dating of sediment core samples and mapping sediment depths will provide information on sedimentation rates and amount of sediment which may have to be addressed.
 - 2. A new sensor is being developed to measure sedimentation and resuspension may help to define the sources and causes of resuspension.

3. Assessment of the potential for phosphorus and metals to be released from the sediments once water concentrations of phosphorus are reduced and if oxygen levels increase.
 4. Analysis of both current deposits and older sediments for metals and organic compounds.
 5. Studies to measure metal concentration in worms from the harbour sediment and look for bioaccumulation of organic contaminants.
 6. Bioassays to determine toxicity of harbour sediment and water.
 7. Identification of sub lethal effects of harbour worms on fish.
 8. Mapping areas of sediment toxicity.
- C. Studies of the sources of silt and suspended solids will enable the writing team to recommend controls of erosion which will improve water clarity in the harbour.
1. Weekly sampling of the tributaries to identify areas of high erosion.
 2. Mapping of rural soil types and agricultural uses.
 3. Investigating urban land uses especially construction projects and recommend corrective actions to reduce erosion.
- D. Additional measurements of flows in the harbour and through the Burlington Canal will:
1. Permit more accurate calculation of nutrient and contaminant budgets for the harbour and
 2. Provide more information on the impact harbour water has on Lake Ontario and vis versa.
- E. Pilot testing of remedial measures include:
1. A project to improve removal of phosphorus at the sewage treatment plants and therefore reduce algal in the harbour.
 2. A study to make more efficient use of the storage capacity in the existing combined sewers and thus reduce overflows.

If successful both could have a beneficial effect on water clarity and oxygen concentration in the harbour.

F. Water quality surveys.

1. Spatial and temporal surveys in ammonia, nitrate, oxygen and water clarity will be performed this field season so that the impact of remedial measures such as ammonia loading reductions can be documented.
2. Comparisons of nearshore and offshore water clarity and processes responsible for the increased water turbidity in the nearshore area will be conducted.

The Remedial Action Plan will be continually revised as new information becomes available. Following release of this draft report "Goals, Problems and Options", the stakeholders and public will have an opportunity to review and comment on the options. The next stage report will identify preferred options, taking into account the stakeholders and public input.

VI.7 PUBLIC INVOLVEMENT

VI.7.1 Educational Opportunities

In the process of identifying goals and future uses for Hamilton Harbour, the Stakeholders concluded that public acceptance of water quality improvement and public support for financing remedial measures, is crucial to successful RAP implementation. The Harbour, its watershed and the ecosystem was identified as an educational resource for students of all ages. The Stakeholders made two recommendations on education:

- 1) That MOE and DOE promote the Harbour as an educational resource;
- 2) That educational programs be developed to change public perception of the condition of the Harbour.

In response to these recommendations a number of Stakeholders formed a sub-committee to make recommendations on educational opportunities.

A periodic newsletter called "Dialogue of Hamilton Harbour" was started in January 1987 to report on activities pertaining to the Harbour and the RAP. The present distribution numbers 2500, and is growing steadily. Issue #5 to be released April 1988 summarizes this "Goals, Problems and Options Report".

Writing team members are available for speaking engagements on a request basis. In 1987, 10 presentations were given at public interest meetings and technical conferences. At the April 13 - 18 Open House at the Canada Centre for Inland Waters (CCIW),

there was a major display theme on Hamilton Harbour, the RAP process and related research projects.

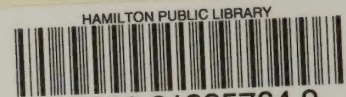
Involvement of the public in the development of the Hamilton Harbour Remedial Action Plan will continue.

VI.7.2 Stakeholders' Role

Public involvement is necessary for defining the goals for water quality improvements, for assessment of the community consensus on what should be done, and for the success of the RAP. A public consultation program aimed at both the citizens, in general, and principle Stakeholders was initiated in 1986. DOE and MOE hired a facilitator to coordinate public input and Stakeholder participation. Currently, there are 49 Stakeholders representing government agencies, municipal officials, institutions, industries and public citizen groups who make use of, have interest in or have jurisdiction over the Harbour. Their role is: to advise the writing team on goals and future uses for the Harbour and to review remedial options to achieve the goals, the costs and benefits of the options.

At a two day workshop in July 1986 and in subsequent meetings in December 1986 and January 1987, Stakeholders refined their goals and prepared an Interim Stakeholders Report. Their two prime principles for the development of the RAP include: the ecosystem approach and zero discharge. Secondary principles include: human health, public acceptance, access to the Harbour and pleasing aesthetics. The Stakeholders identified desired future uses for the Harbour as recreational boating, a self-sustaining warmwater fishery, swimming, wildlife habitat and use as an educational resource. A warmwater fishery is considered the key goal, both for its intrinsic value as well as a measure of an adequately functioning aquatic ecosystem.

In March 1987, Stakeholders and public reviewed the first Interim RAP report and gave comments to the writing team. At each stage, Stakeholder views and recommendations have been incorporated into the development of the plan. Following release of this report on the Analysis of Options, Stakeholders and the public will have another opportunity for input.



Remedial Action Plan Plan d'Assainissement

Canada Ontario 

Canada-Ontario Agreement Respecting Great Lakes Water Quality
L'Accord Canada-Ontario relatif à la qualité de l'eau dans les Grand Lacs